

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
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1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE JULY 1979		3. REPORT TYPE AND DATES COVERED
4. TITLE AND SUBTITLE REPORT EVALUATION OF NORTH BOUNDARY PILOT CONTAINMENT SYSTEM (NBCS), ROCKY MOUNTAIN ARSENAL, DENVER, COLORADO				5. FUNDING NUMBERS
6. AUTHOR(S)				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) D'APPOLONIA CONSULTING ENGINEERS, INC.				8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) BATTELLE COLUMBUS LABORATORIES COLUMBUS, OH				10. SPONSORING / MONITORING AGENCY REPORT NUMBER B7900055
11. SUPPLEMENTARY NOTES 20000501 062				
12a. DISTRIBUTION / AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED				12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) AN INDEPENDENT COMPARISON OF PLANNED DESIGN PERFORMANCE AND THE OBSERVED PERFORMANCE OF THE NORTH BOUNDARY PILOT CONTAINMENT SYSTEM. SPECIFIC TASKS INCLUDED IN THE PROGRAM FOLLOW: 1) REVIEW DESIGN PERFORMANCE PREDICTIONS OF THE DEWATERING AND RECHARGE WELL SUBSYSTEMS AND WATER LEVEL FLUCTUATIONS OF THE SURROUNDING MONITORING WELLS, 2) REVIEW ACTUAL PERFORMANCE DATA OF THE DEWATERING AND RECHARGE WELL SUBSYSTEMS AND WATER LEVEL FLUCTUATIONS FOR THE SURROUNDING MONITORING WELLS, 3) COMPARE ACTUAL AND PREDICTED PERFORMANCE DATA, AND 4) PROVIDE EXPLANATIONS FOR OBSERVED DIFFERENCES, AS APPROPRIATE, BETWEEN ACTUAL AND PREDICTED PILOT CONTAINMENT SYSTEM PERFORMANCE. FOR THIS COMPARISON, ONLY THE EFFECT OF THE NORTH BOUNDARY PILOT CONTAINMENT SYSTEM ON (A) THE ALLUVIAL AQUIFER SYSTEM VICINITY AND (B) THE REMOVAL OF THE CONTAMINANTS DIMP AND DCPD FROM THE GROUNDWATER SYSTEM ARE CONSIDERED.				
14. SUBJECT TERMS AQUIFER, GROUNDWATER HYDROLOGY, HYDROGEOLOGY, DIMP, DCPD				15. NUMBER OF PAGES 61
				16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED		18. SECURITY CLASSIFICATION OF THIS PAGE		19. SECURITY CLASSIFICATION OF ABSTRACT
				20. LIMITATION OF ABSTRACT

81266R45

Rocky Mountain Arsenal
Information Center
Commerce City, Colorado

Report

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Evaluation of North Boundary Pilot Containment System

B7900055

D'APPOLONIA

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EVALUATION OF ROCKY MOUNTAIN ARSENAL NORTH BOUNDARY PILOT CONTAINMENT SYSTEM

1.0 INTRODUCTION

The Rocky Mountain Arsenal (RMA) is located approximately 10 miles northeast of the central business district of Denver, Colorado and immediately north of the Stapleton International Airport (Figure 1). This facility has been utilized for manufacture or detoxification of various organic chemicals since the early 1940's. Industrial wastes generated by these operations have been discharged to several waste basins located south of the pilot containment system (Figure 1). The first reported indication of groundwater contamination associated with RMA activities was in 1954 when several farmers north of the arsenal complained of damage to crops irrigated with water pumped from the alluvial aquifer (Kolmer and Anderson, 1977b). A new disposal basin with a low permeability liner (Reservoir "F") was completed in 1957 for the purpose of alleviating the contamination problem. In 1974, diisopropylmethylphosphonate (DIMP) and disycloenladine (DCPD) were found to be present in waters discharging from a bog located along the north boundary of the RMA. DIMP was also detected in water supply wells for the city of Brighton in December of 1974. The off-post detection of DIMP and DCPD prompted the Colorado Department of Health to issue three Cease and Desist Orders on April 7, 1975 that required an immediate stop to the surface and subsurface discharge of DIMP and DCPD, development of a plan to preclude future discharge of the contaminants, and development of a monitoring program to verify compliance with the orders.

From 1975 to 1977, several investigators were involved in hydrologic investigations and the design of a contaminant containment and treatment system for a portion of the northern boundary of the RMA. These studies and reviews were conducted by Konikow (1975), Reynolds (1975), Miller (1977), Mitchell (1976), Kolmer and Anderson (1977a and b), Thomas, et al., (1977), and Robson (1977). The studies resulted in the installation of the present pilot containment system along a portion of the northern RMA boundary (Figure 1).

D'Appolonia Consulting Engineers, Inc., (D'Appolonia) was retained by Battelle Columbus Laboratories under Scientific Services Agreement Delivery Order No. 1245 to provide an independent comparison of planned design performance and the observed performance of the north boundary pilot containment system. Specific tasks included in the program follow:

- Review design performance predictions of the dewatering and recharge well subsystems and water level fluctuations of the surrounding monitoring wells.
- Review actual performance data of the dewatering and recharge well subsystems and water level fluctuations of the surrounding monitoring wells.
- Compare actual and predicted performance data.
- Provide explanations for observed differences, as appropriate, between actual and predicted pilot containment system performance.

For this comparison, only the effect of the north boundary pilot containment system on (a) the alluvial aquifer system in the vicinity and (b) the removal of the contaminants DIMP and DCPD from the groundwater system are considered. The sources of information used in this evaluation are identified in the attached bibliography.

2.0 DESCRIPTION OF NORTH BOUNDARY PILOT CONTAINMENT SYSTEM

A pilot containment system was designed and installed along the north boundary of the Arsenal to demonstrate compliance with the Cease and Desist Orders. The pilot containment system, as implemented, consists of the following elements:

- Dewatering wells subsystem
- Treatment plant
- Recharge wells subsystem
- Impermeable barrier
- Monitoring subsystem

A flow schematic and plan layout of these elements are shown in Figures 2 and 3, respectively. The location of monitoring points relative to the north boundary pilot containment system and surface topography are shown in Figure 4. The operation of the north boundary pilot containment system began on July 25, 1978. Data from monitoring wells in the north boundary area are available prior to the startup.

The operation of the pilot containment system relies on an impermeable groundwater barrier to stop the flow of contaminated water. Dewatering wells on the upgradient side of the barrier remove water from the aquifer for treatment while recharge wells on the downgradient side of the barrier inject the treated water back into the aquifer. Brief descriptions of each of the subsystems follow:

- Dewatering Well Subsystem - This system consists of six 8-inch diameter wells installed within 30-inch diameter gravel packed holes. The wells are approximately 230 feet apart, and are screened through the full thickness of the alluvial aquifer. Each well has a submersible pump and flow control system. The pumping system is designed to maintain a constant head within each well. This is accomplished by means of a level sensing probe controlling a motorized valve at the wellhead that will cause the water pumped to be recycled back into the well when the pumping level drops below the cutoff probe (personal communication with John Wardell).

- Treatment Plant Subsystem - A schematic flow diagram illustrating components of the treatment plant subsystem is presented in Figure 2. The contaminated dewatering well effluent is discharged to a sump from which it is pumped through a dual media filter to remove suspended solids. The filtered water is then circulated through two activated granular carbon columns. DIMP and DCPD are adsorbed by the activated carbon and the treated effluent is then discharged by gravity drainage to the recharge well subsystem. The current design capacity of the treatment plant is 10,000 gallons per hour (Kolmer and Anderson, 1977b).
- Recharging Well Subsystem - The recharge well subsystem consists of twelve 18-inch diameter, wells installed within 36-inch diameter gravel packed holes. The wells are typically spaced at about \pm 115 feet. These wells are also screened the full thickness of the aquifer. The water level is maintained below a maximum level by a float control valve. If the water level in the recharge well rises above the preset maximum level then no water is discharged to that well.
- Impermeable Barrier - This component of the system is a bentonite slurry wall separating the dewatering well line from recharging well line. The function of this wall is to physically cut off the natural movement of groundwater through the aquifer for the purpose of isolating the upgradient and downgradient flow. In the completed containment system, this barrier will preclude mixing of potentially contaminated and treated waters.
- Monitoring Wells - The monitoring wells are a series of observation holes distributed both upgradient and downgradient of the pilot containment system (Figure 4). These observation wells are completed with small diameter PVC casing screened within the alluvial aquifer. Water levels and chemical quality of the groundwater are monitored periodically at various of these wells.

3.0 SITE HYDROGEOLOGY

3.1 AQUIFER DESCRIPTION

In and around the north boundary pilot containment system, the aquifer of concern is composed of unconsolidated well-sorted sands and sandy gravels. The well-sorted sand unit comprises the majority of the productive aquifer thickness. This unconsolidated aquifer is in contact with low permeability claystone bedrock of the Denver Formation. Due to the great difference in permeability between the consolidated claystones and the sand and gravel aquifer, the bedrock is assumed to act as an impermeable lateral and lower boundary. Overlying the productive aquifer units are silty sands and clays. The depth to the top of the alluvial aquifer is typically less than 15 feet. The alluvial aquifer has a cross-sectional width of approximately 5,000 feet in the vicinity of the northern boundary of the RMA. The eastern and western aquifer boundaries are formed by thinning of alluvial deposits over bedrock highs.

The plan view of the locations where the bedrock highs cause a thinning of the alluvial deposits are identified in Figure 4 as aquifer boundaries; these are approximate and based on the available data. A diagrammatic geologic cross-section along a portion of the north boundary of the RMA is presented in Figure 5. The alluvial deposits fill an ancient valley cut into the bedrock. Typically, the alluvial aquifer is thicker near the eastern aquifer boundary where the maximum saturated thickness of about 15 feet occurs. The aquifer thins to about 3 feet near the western bedrock high, where the pilot containment system has been located.

Recharge to the aquifer is by infiltration of rainwater and snowmelt and possibly by leakage of the various surface impoundments located on the Arsenal grounds. The average annual precipitation is 15.5 inches per year (Kolmer and Anderson, 1977b). The potentiometric surface of the aquifer is lowered during the summer growing season (when evapotranspiration is high) and rises in the fall, winter, and spring. The magnitude of the seasonal fluctuation is as much as 2.5 feet (Mitchell, 1976).

3.2 GROUNDWATER HYDROLOGY

Groundwater in the alluvial aquifer occurs under both confined (potentiometric level above the top of the aquifer) and unconfined conditions (potentiometric level below the top of the aquifer) depending on the specific location. For example, along the northern RMA boundary, the aquifer is confined along the eastern end and unconfined along the western end near the pilot containment system. Whether the aquifer is confined or unconfined is also dependent on the time of year because the water levels rise or fall in response to recharge. The preoperational potentiometric surface map is provided in Figure 6. This map was developed using potentiometric level information for the months of February and March 1978. The gradient on the potentiometric surface ranges from 0.0067 to 0.0086 trending toward the north in the vicinity of the north arsenal boundary. Where data is available, the potentiometric contours coincide approximately with the potentiometric maps developed by Robson (1976).

Aquifer tests have been conducted at numerous locations in the vicinity of the northern RMA boundary in both 1976 and 1978 by the Corps of Engineers, Waterways Experiment Station (WES). The work completed in 1976 (Mitchell, 1976) included formal aquifer tests at three locations along the northern RMA boundary. Each of these test wells had a battery of piezometers installed at various distances for water level measurements during the test pumping. The results of this initial testing program estimated permeabilities in the alluvial aquifer to be about 1,500 gpd/ft² (200 ft/day). The results of this testing program demonstrated considerable variability due to the widely fluctuating pumping rates during the tests. Subsequent reanalysis of the data from this test was completed by Battelle-Moody (Thomas, et. al., 1977) and their analysis was in substantial agreement with the WES results. In addition, a storage coefficient of 0.05 was estimated during this reanalysis (Thomas, et al., 1977). These analyses were used for design and development of performance projections for the pilot containment system.

In 1978, five additional aquifer tests were conducted by WES at various locations in the alluvial aquifer south of the north boundary pilot containment system (Vispi, 1978). These tests were conducted for a

considerably greater length of time than those conducted in 1976 and constant discharge rates were maintained for the duration of each of the tests. These two factors resulted in a more reliable estimate of the alluvial aquifer characteristics. The range in permeabilities found during this second testing program was from 793 gpd/ft² (106 ft/day) to 9,690 gpd/ft² (1,295 ft/day). In the vicinity of the north boundary pilot containment system, the tests indicated permeability in the range of 3000 gpd/ft² (400 ft/day). Results of testing at Borehole No. 345 near the eastern side of the northern RMA boundary (Figure 4) were selected as representative of alluvial aquifer characteristics. The testing at this location yielded a permeability estimate of approximately 3000 gpd/ft² (400 ft/day).

The transmissivity calculated by Vispi (1978) for this pump test was used in this investigation to estimate permeabilities for sand and sand and gravel units in the alluvial aquifer. The permeability contrast between the sand and gravel unit and the sand unit was estimated by D'Appolonia to be 60 percent, i.e., sand permeability is 60 percent of sand and gravel permeability. When the respective sand unit and sand and gravel unit (relatively thin at this location) thicknesses at Borehole No. 345 were used in conjunction with the estimated permeability ratio, permeabilities of about 3,000 gpd/ft² (400 ft/day) for the sand and about 5,000 gpd/ft² (668 ft/day) for the sand and gravel unit were calculated.

In order to estimate an approximate flow across the width of the alluvium along the northern RMA boundary, saturated aquifer unit thicknesses from boring logs and the permeability information defined above were utilized. At selected locations, where borehole information is present, the transmissivity for a one-foot wide section of saturated aquifer (both the sand unit and sand and gravel unit) was calculated using the following equation:

$$T_{\text{total}} = T_{\text{sand}} + T_{\text{sand and gravel}} \quad (1)$$

T is the transmissivity and is determined by:

$$T = K \cdot m \quad (2)$$

where:

K = permeability ($K_{\text{sand}} \approx 3000 \text{ gpd/ft}^2$ and

$K_{\text{sand and gravel}} \approx 5000 \text{ gpd/ft}^2$)

m = saturated thickness of aquifer unit (determined from the borehole log using average water levels)

This is an approximation due to use of average saturated thickness. The transmissivity for the total thickness of saturated aquifer at various borehole locations is plotted in Figure 7.

In order to establish a flow rate at each of the specific locations, the following equation is used:

$$Q = T \cdot i \quad (3)$$

where:

Q = flow rate (gpd) for a one-foot width

T = Transmissivity (gpd/ft)

i = Gradient (feet per foot)

Kolmer and Anderson (1977b) measured a gradient (i) of 0.0067 ft/ft. Using the information presented in Figure 6 (data base February and March, 1978), a gradient of about 0.0086 ft/ft was measured for this investigation. A flow rate was calculated at specific borehole locations using both gradient values. The results of these calculations are presented in Figure 7. In order to obtain the total flow across the northern RMA boundary, the area under the flow rate curve (Figure 7) was calculated. For a gradient of 0.0067 ft/ft, the total flow was calculated to be approximately 43,000 gallons per hour (gph) and for the gradient of 0.0086 ft/ft the total flow was approximately 55,000 gph.

The velocity of the groundwater flow varies with the permeability and gradient changes across the northern RMA boundary. Using the estimated average permeability of 400 ft/day and an average gradient of 0.0086

ft/ft, the Darcian velocity of $3.44 \text{ ft}^3/\text{ft}^2$ day is estimated. By dividing this value by an estimated effective porosity of 30 percent (Lambe and Whitman, 1969), an actual pore velocity of 11.5 ft/day is estimated under the natural gradient for the February to March, 1978 period.

3.3 PREOPERATIONAL DISTRIBUTION OF SELECTED CHEMICAL PARAMETERS

The contaminant concentration maps presented in this report were prepared using data provided by RMA (1977, 1978, and 1979). For selected periods, concentration data was plotted for various contaminants. This information was then contoured using linear interpolation between known data points. Variance to the linear interpolation procedure occurred in only a few localized instances, where a temporal comparison with other maps of the same contaminant suggested a more realistic contour location. It is acknowledged that groundwater dispersion of chemical species is not expected to be a linear function and that the contours presented could change if substantially more data were gathered. However, for the purposes of a graphical display of gross temporal changes in the groundwater chemistry, the above described method of contouring is consistent, useful, and adequate.

The contaminant DIMP was present throughout the alluvial aquifer in the north boundary area. Reported DIMP concentrations from the period June through December, 1977, and June and July, 1978 were plotted and contoured in Figure 8. Considering the mixture of data, Figure 8 provides a very approximate graphical description of the presystem distribution of DIMP. The highest detected concentrations occurred at Monitor Wells 313 [10,600 micrograms per liter ($\mu\text{g}/\text{l}$)], 47 (3514 $\mu\text{g}/\text{l}$), and 13 (3360 $\mu\text{g}/\text{l}$). Concentrations were relatively low (<500 $\mu\text{g}/\text{l}$) in the vicinity of Monitor Wells 306 (136 $\mu\text{g}/\text{l}$), 8-Section 23 (21 $\mu\text{g}/\text{l}$), 11 (11 $\mu\text{g}/\text{l}$), 10 ($\mu\text{g}/\text{l}$), 2 (71 $\mu\text{g}/\text{l}$), 8-Section 24 (483 $\mu\text{g}/\text{l}$), and 9 (364 $\mu\text{g}/\text{l}$).

A DCPD concentration map (Figure 9) to describe approximate presystem conditions was prepared in a similar manner. The majority of the area showed relatively low concentrations (260 $\mu\text{g}/\text{l}$ or less). However, in the vicinity of the intersection of Tenth Avenue and Peoria Street

preoperational concentrations as high as 2290 $\mu\text{g}/\text{l}$ were measured (Monitor Well 43). Work by Mitchell (1976) identified a definite plume of DCPD concentration extending downgradient from Reservoir "F". The available data for 1977 and 1978 do not confirm the presence of this plume.

A presystem chloride concentration map was also developed (Figure 10). Chloride concentrations are used in this report primarily as a reference because they are typically nonreactive with the aquifer media and are not removed by the pilot plant treatment system. The presystem chloride distributions are somewhat similar in pattern to DIMP distributions. Monitor Well 313 [2240 milligrams per liter (mg/l)] had a relatively high concentration. Monitor Wells 309 and 13 showed 613 mg/l and 822 mg/l , respectively. Other well data typically showed concentrations less than 500 mg/l .

4.0 PILOT CONTAINMENT SYSTEM PERFORMANCE PREDICTIONS

4.1 BASIC ASSUMPTIONS AND PREDICTIVE MODEL

In comparing the predicted pilot system performance with actual performance, the assumptions and model used in developing the prediction were examined. The model was based on the confined equilibrium radial flow form of Darcy's equation. The form of the equilibrium equation used to predict performance in the final EIS (Kolmer and Anderson, 1977b) follows:

$$h(x,y) = \frac{1}{4\pi} \sum_{i=1}^n \frac{Q_i}{T_i} \ln [(x-x_i)^2 + (y-y_i)^2] + C \quad (4)$$

where:

h = drawdown

x,y = cartesian coordinates of point for which drawdown is to be determined

Q_i = discharge rate at well i

T_i = transmissivity at well i (assumes confined conditions)

x_i, y_i = pumping well location

C = constant (function of configuration of well system, Q , T and radius of influence)

The two critical parameters in the hydrologic analysis are the permeability of the aquifer and the radius of influence of the wells. The predictions were based on permeabilities of 200 ft/day (1,500 gpd/ft²) in the thicker portion of the aquifer on the east end of the pilot system while a permeability of 150 ft/day (1,120 gpd/ft²) was used for the western side of the pilot containment system. The basis for the lower permeability on the western side is that the grain size of the sediments is normally finer. The estimate of radius of influence was set at 500 feet due to lack of response of observation piezometers at

that distance during short term pumping tests. The Theis nonequilibrium equation was used to estimate the time it would take the radius of influence to reach the distance of 500 feet; that equation follows:

$$s = \frac{Q}{4\pi T} \int_{\frac{r^2 S}{4Tt}}^{\infty} \frac{e^{-u}}{u} du \quad (5)$$

where:

$$u = \frac{r^2 S}{4Tt}$$

s = drawdown

r = distance from pumping well to observation point

S = storage coefficient

e = natural logarithm base

t = time of pumping

T = transmissivity

Q = pumping rate

(Kolmer and Anderson, 1977b)

The storage coefficient is the only additional parameter necessary for this evaluation.

The presence of the impermeable barrier was simulated by the use of image wells symmetrically located about the slurry wall. The use of image wells allows simulation of a no flow boundary at the slurry wall. The form of the nonequilibrium equation used to solve for drawdown at each well involves a summation or superposition of drawdown components from each well and each image well. The equation is as follows:

$$s = \sum_{i=1}^n \frac{Q_i}{4\pi T_i} \int_{\frac{r_i^2 S}{4T_i t}}^{\infty} \frac{e^{-u}}{u} du \quad (6)$$

The definition of terms is the same as in Equation 5.

This was based on a storage coefficient of 0.03 which was determined from the 1976 testing program. The nonequilibrium equation matched the drawdowns from the equilibrium equation after seven days. When the drawdowns from these two solutions match, that signifies the transient expansion of the cone of influence reached the assumed radius of influence at the end of seven days.

Table 1 is reproduced from information presented in the final EIS and compares the predicted pumping rates and drawdowns at the seven day (calculated equilibrium) drawdown with the observed system pumping rates and drawdowns after ten days of operation. A more direct comparison is achieved by employing the actual pumping rates observed in the first ten days of system operation with the nonequilibrium predictive model of Kolmer and Anderson (1977b). The modified nonequilibrium predictions are shown in Table 2. Since the first available data on drawdown was collected at ten days after the startup, the predicted drawdown at this time was also calculated and shown in the table. The comparisons indicate that the observed drawdowns were smaller on the eastern side of the dewatering well line than were predicted (Table 2). Response at the western side is somewhat ambiguous with some wells showing greater drawdown and others less drawdown than predicted.

The discrepancy between the predicted drawdowns and the results of the 1978 aquifer testing program suggest that the predictive model should be updated. Examination of data collected since 1977 and reconsideration of the assumptions associated with the 500 feet radius of influence indicate that a greater influence radius occurs. Factors that would allow an equilibrium condition to be reached at the 7-day pumping period would include the following:

- Surface recharge
- Leakage from overlying or underlying aquifers
- Induced infiltration

None of these factors are anticipated to contribute sufficient quantities of water to the aquifer to allow equilibrium to be approached at time periods as small as seven days. The nonequilibrium equation used

by Kolmer and Anderson was evaluated to estimate how far the cone of influence of the system might spread in one year of operation and the results show a radius of about 3,000 feet to be more appropriate to approximate equilibrium conditions. Supportive evidence for this larger area of influence is provided by declines in water levels for wells located over 1,000 feet from the dewatering wells. Examination of water level data near the dewatering wells also indicates that declines continued nominally for 30 to 60 days before the changes become undetectable. This is considerably in excess of the seven days predicted to reach equilibrium conditions.

Based on the comparisons and the additional data now available a new predictive model was implemented. In order to duplicate the response characteristics of the alluvial aquifer in the pilot containment system area, a well field simulator was developed. The simulator solves the Theis nonequilibrium equation for each pumping or injection well and simultaneously superimposes the solution on each of the other wells in the simulation. The barrier effects were simulated by including image wells to yield a no-flow boundary at the slurry wall barrier. This model includes corrections for decreasing saturated thickness near the wells using Glover's second approximation (Glover, 1974).

Parameter values for the simulation of dewatering well performance were estimated from results of the pumping test at Borehole No. 345 (Vispi, 1978). Permeabilities of $1,500 \text{ gpd/ft}^2$ (200 ft/day) were used for the two westernmost wells (320 and 321) in the dewatering line; permeabilities of approximately $3,000 \text{ gpd/ft}^2$ (400 ft/day) were used for the remaining wells. The lower permeability was estimated at the western edge of the pilot system due to the finer grain nature of the aquifer at that location. A storage coefficient of 0.10 was conservatively estimated for the unconsolidated sands and gravels [the value used in Theis design prediction was 0.03 (Kolmer and Anderson, 1977b)]. The value of 0.10 is considered to be representative for long-term pumping due to greater drainage of pore space over long time periods.

The responses of individual dewatering wells were used to calibrate the well field simulation model. The simulator plan view of the pumping wells and image wells are shown in Figure 11. The parameter values for the calibrated simulation are provided in Table 3. Imaginary observation wells were incorporated with the model to check the response of the aquifer at various distances from the dewatering line. The distances of these imaginary observation wells corresponds approximately to the real observation wells. Actual average pumping rates over the first 60 days of operation were simulated and the permeabilities in the model adjusted as necessary to duplicate the response of the actual system. The calculated drawdowns at 60 days are compared with observed drawdowns in Table 4. The observed drawdowns are not shown at the observation wells due to the 'noisy' nature of the data i.e., the normal water fluctuations are of a similar magnitude to the water level response to pumping. The ability to match observed-to-calculated system responses by using permeabilities of approximately 3,000 gpd/ft² (400 ft/day) as found by Vispi (1978) suggests that these permeabilities are realistic.

The well field simulation model has certain inherent limitations. Complex boundary effects related to both lateral changes in transmissivity and the physical barrier effects of the bedrock highs complicate the actual system. The equations used in the simulation assume a homogeneous, isotropic and infinite aquifer system. The equations used also assume no change in transmissivity as a function of drawdown. This limitation is at least partially resolved by using Glover's (1974) approximation modification of the Theis equation to correct for decreasing saturated thickness in the vicinity of a pumping well.

Another prediction of system performance made in the EIS was that the total groundwater flux across the 1,400 foot barrier alignment equalled 4,200 gallons per hours, using a gradient of 0.0067. Calculations of the groundwater flux based on these updated analyses show a 12,000 gallons per hour groundwater flux across the barrier alignment. The primary reason for the higher flow estimate is the increased permeability that has been determined to be more representative. The

analysis indicates that only about 1/3 of the natural flow is being diverted through the treatment system, with the remaining flow going around the barrier. This item is further addressed in the following discussion.

5.0 EVALUATION OF SYSTEM PERFORMANCE

5.1 EFFECTS ON HYDROLOGIC SYSTEM

Operation of the pilot containment system has had a significant impact on observation wells near the containment system but, outside of the effects local to the pumping-recharge zone, there is no significant effect on the prevailing potentiometric surface. Figure 12 illustrates the areal potentiometric surface during system operations. Larger scale potentiometric surface maps showing details around the system are presented in Figure 13 and 14. The maximum drawdown has been 4.56 feet at Dewatering Well No. 320 and the maximum build-up has been 8.27 feet at Recharge Well No. 332. Away from the dewatering and recharge wells the water level changes have been less. The maximum amounts of drawdown or build-up for any given well are difficult to determine because detailed preoperational data is not available for the wells close to the dewatering and recharge wells. The natural water level fluctuations tend to obscure the changes at wells further from the plant (over 250 feet). Relative drawdown and build-up values have been derived from interpreting preoperational trends of the water levels for those wells in the estimated radius of influence (less than 3,000 feet from the dewatering wells) and comparing these trends with wells over 3,000 feet from the dewatering wells. Analyses of water level trends indicate that declines of less than one foot have occurred for wells located over 1,000 feet from the dewatering wells. On the recharge side, water level build-ups have typically been less than two feet for wells located within 200 feet of the recharge wells.

The amount of water diverted from the flow system through the plant has averaged 3,000 gallons per hour and the estimated natural flow through this section of the northern boundary is approximately 12,000 gallons per hour. Examination of the potentiometric maps around the pilot containment system (Figures 13 and 14) indicates that the excess flow is being diverted around the barrier. This indication is based on deflection of contour lines.

In addition to a change in orientation of flow vectors in the vicinity of the slurry wall, a localized change in gradient is indicated. This change in gradient is based on a comparison of the contours in the vicinity of the slurry wall and area away from the wall. An increase in water levels would be expected at monitoring wells around the margin of the barrier if flow is taking place around the barrier. No preoperational data is available in these areas to confirm this hypothesis. The rise in water level necessary to accommodate the increased flow around the barrier amounts to only a few tenths of a foot; such a small increase cannot be distinguished from other influences.

Regionally, the natural water level gradients have not changed appreciably due to system operation with the gradient across the northern arsenal boundary being between 0.006 and 0.0125 both before and after system installation (Thomas, et al., 1977). In comparing water level trends for the wells in the area of the plant with those over 3,500 feet away, it is concluded that the pilot plant does not influence regional gradient changes.

5.2 TREATMENT PLANT EFFECTIVENESS

Chemical quality of the filter effluent and the adsorber (activated carbon column) effluent is monitored within the plant at close intervals. Comparison of the chemical analysis of the filter effluent with the adsorber effluent indicates that only organic compounds are removed by the adsorber and the inorganic compounds remain unchanged. DIMP and DCPD are the major constituents of the organic fraction. Other organic compounds are also indicated in the analysis to be present as minor but consistent constituents of the filter effluent.

Using the flow rate data for dewatering wells and daily organic chemical concentration data, the cumulative recovery rates for DIMP and DCPD were calculated. Figure 15 is the plot of cumulative weight recovered by the plant versus time. During an eight month operation of the plant for which data was available, about 73 kilograms of DIMP and 67 kilograms of DCPD were recovered.

Changes in the slopes of these graphs could be indicative of any or all of the following factors:

- Variation of flow through the plant.
- Variation in the concentration of a given constituent in the inflow.
- Failure of the adsorber.

Adsorber failure for DIMP recovery occurred once during November and December 1978, as evidenced by slight flattening of the DIMP recovery graph. As can be seen in the flow histogram, the flow rate was increased in late August 1978. The steepening of the slope of the DIMP graph is evidently the result of the flow increase. The increase in the slope of the DCPD graph that occurred in early September 1978 is attributed to a change in the inflow concentration of DCPD, as no changes in the flow rate or plant removal function occurred at this time.

If flow through the plant is constant and the adsorber is functioning properly, a constant decrease in the slope would indicate decrease in concentration in the inflowing water. This could be due to either of the two reasons:

- General improvement in quality of water up-gradient from the plant.
- Recirculation of the treated water through the aquifer in the vicinity of the plant.

The absence of any overall flattening of the slope on the cumulative recovery curve suggests that neither of these phenomenon are occurring. Examination of the potentiometric surface map during system operation indicates that no gradient is present that would cause recirculation.

5.3 RELIABILITY OF WATER QUALITY DATA

Examination of organic water quality analyses from monitoring wells shows that significant unexplained variation is present. Several of the monitoring wells show nearly order of magnitude fluctuations in

concentration of DCPD and DIMP suggesting either sampling or analysis errors. Even though there is much variation in the data, the reliability is adequate to evaluate system performance when examined on an overall bases. A series of maps showing the concentration distribution at closely spaced times were constructed for DIMP, DCPD and chloride. The dates for the maps were chosen so a map prior to system installation and several maps during the operation of the pilot containment system could be examined and a comparison made. These maps are presented in terms of concentration bands that are generally based on linear interpolation between observed data points. It is noted that data is not available from identical sampling locations for each map.

5.4 EFFECT ON DIMP CONCENTRATIONS

The concentrations of DIMP prior to installation of the pilot containment system are shown in Figure 8. Three maps showing DIMP concentrations in September-October, November-December, and March are presented in Figures 16, 17, and 18 respectively. Concentrations after plant startup on the upgradient side remain relatively consistent. Trends are difficult to distinguish due to the fact that different wells were sampled at different times. Concentrations on the downgradient side of the barrier show the effects of recharge of treated water. The plume of low DIMP concentration spreads faster near the east end of the recharge line, based on the change in shape of the 0-500 concentration band between the presystem map (Figure 8) and the September-October, 1979 map (Figure 16). The November-December, 1978 map (Figure 17) shows some increase in concentrations in the central portion of the aquifer directly downgradient from the barrier and also a rise of lesser magnitude along the eastern edge. This rise in concentration may be due in part to the break-through of DIMP that occurred from mid-November to mid-December when output levels of DIMP from the carbon column ranged up to 500 $\mu\text{g}/\text{L}$. The March, 1979 concentration map (Figure 18) shows the effects of localized injection quite clearly. Nearly the entire flow of the plant was diverted to the three eastern recharge wells beginning in January. This resulted in a decrease in concentration downgradient of the three

wells to a level only several times higher than the injected (treated) concentration. Concentrations on the west side of the pilot system showed an increase suggesting migration of contaminated water around the west end of the barrier.

5.5 EFFECT ON DCPD CONCENTRATIONS

As was predicted (McNeill, 1977), the present system does not intercept the main DCPD plume as shown on the preoperational concentration map (Figure 9). However, Figures 19 and 20 indicate diversion of part of a DCPD plume towards the pilot containment system area due to system operation. Figure 19 (September-October, 1978) shows concentrations three months after the plant was in operation. Comparison of Figures 9 and 19 show that in three months of operation the concentrations upgradient of the system have increased around the easternmost pumping wells but have been decreased immediately downgradient of the recharge system.

By March 1979 (Figure 20) DCPD plume was still moving towards the pilot plant although concentrations were decreasing slightly upgradient of the plant. Improvement in quality can be seen farther downgradient from the plant than on previous maps. Figure 20 illustrates a similar concentration pattern for DCPD as was observed for DIMP around the recharge wells for the period when all of the treated water was recharged through the three easternmost wells. In Figure 20, it can also be seen that the diverted DCPD plume is being moved downgradient from the dewatering wells.

5.6 CHLORIDE CONCENTRATION

Since the plant does not remove any chloride, this ion was used as a check to see if similar trends as those of DIMP and DCPD could be observed. Figure 10 shows chloride concentration prior to system operation. Relatively high concentration of chloride can be seen around the plant area just a week before the pilot plant started operation (July 25, 1978). Figure 21 (March 1979) shows chloride concentrations eight months after the system was in operation. High concentrations were

still present around the pilot plant except immediately upgradient of the barrier and towards the west of the plant. This low concentration is possibly due to movements of fresh water from a source to the west towards the plant due to the dewatering system.

A monitoring well located about 3,500 feet northwest of the plant (Well No. 313) shows improvement in quality both in chloride and DIMP (Figures 18 and 21). The simultaneous improvement in these components may suggest local recharge dilution. It is doubtful that the operation of the plant has affected this well as theoretical computations show that it would take more than one year for any effect to be seen in this well. In future years the chloride distribution may be valuable for illustrating regional flow system changes.

5.7 DISCREPANCIES IN THE WATER QUALITY DATA

If the pilot containment system was functioning properly, a decline in the DIMP and DCPD values for wells located downgradient from the recharge wells would be expected. As can be seen in Figures 8, 18, 9, and 20 there has been an improvement in quality in the wells located immediately downgradient from the recharge wells. Monitoring wells located further away show little or no measurable improvement up to this time.

Some concern has been expressed as to why the quality data, particularly DIMP, for downgradient wells does not show a continuous improvement in quality. The apparent inconsistencies in the data may be explained by changes in the plant operation. In November and December, 1978 the activated carbon filter had a "break through" and significantly less DIMP was removed by the adsorber during this period. This resulted in a rise in DIMP values in downgradient wells as compared to the September-October (1978) data (Figures 16 and 17).

Beginning in January 1979, all of the recharge was placed in the three eastern wells. This resulted in higher water levels in this area (Figure 14) as compared with the previous potentiometric surface (Figure 13). As the treated water was still being recharged in the eastern

wells, the wells downgradient show low DIMP and DCPD values (Figures 18 and 20). The wells located downgradient from the inoperative recharge wells exhibit a definite rise in contaminant levels. This indicates that some contaminated water is flowing around the barrier along the western edge of the impermeable barrier.

A theoretical pollutant movement calculation was made to determine the temporal position of a broad front plume of treated water (Bouwer, 1978). The dispersion equation allows estimation of concentration when groundwater velocity and dispersion coefficients are known. The dispersion equation allows for the fact that the plume does not move as a unit with a sharp concentration boundary between contaminated and treated water. Dispersion coefficients for the alluvial aquifer were from work conducted by Robson (1977). The results of these calculations are provided in Figure 22. The equations are set up so the water in the treated plume is treated as a tracer concentration. The uppermost curve for a resultant concentration of 1.1×10^{-5} times the input concentration can be taken as the first arrival of trace amounts of the treated effluent. In a practical sense, concentrations of this magnitude cannot be detected. The middle curve shows the arrival of the 50 percent concentration line, i.e., water at the observation point consists of 1/2 water at the initial concentration and 1/2 at the treated plume concentration. The lower curve shows concentration levels equal to input concentration signifying complete flushing of the aquifer with treated effluent. These long travel times partially explain why little general improvement in water quality has taken place on the downgradient side of the pilot containment system.

Due to the number of complicating factors involving the concentrations of contaminants in wells downgradient of the barrier, it is not prudent to determine if the system is functioning properly by doing a statistical analysis on the water quality data. Changes in plant operation, diversion of contaminated water around the barrier, and long pollutant travel times obscure any statistical trends that may show improvement in quality.

6.0 CONCLUSIONS

Based on the following reasons, it is concluded that the north boundary pilot containment system is removing contaminated water from the aquifer, removing the organic contaminants, and returning the treated water to the aquifer:

- The plumes of treated water correspond with the location of the recharge points.
- The cumulative recovery graphs show a continued recovery of contaminants in the treatment plant over the period of operations.
- A DCPD plume has been diverted into the dewatering wells but no corresponding increase in DCPD is noted in the wells downgradient of the recharge wells. Arrival of this plume at the plant is marked by the increase in early September of the slope of the cumulative recovery graph.
- Theoretical dispersion calculations show that no dramatic improvement in downgradient water quality is expected after only one year of operation.

For the following reasons it is concluded that the pilot containment system is not diverting the entire flow of the aquifer that was flowing across the barrier alignment through the treatment plant:

- The water level contours show an increase in gradient around the edge of the barrier indicating an increase in flow.
- The total volume of water being pumped by the dewatering wells is only about 30 percent of the total flow through this section of aquifer based on our estimates.
- The concentrations of contaminants increased in wells downgradient of the westernmost recharge wells when the flow to those recharge wells was stopped as it was in January 1979. This indicates migration around the western edge of the barrier is taking place.

- The concentration map for DCPD of March 1979 (Figure 17) shows the plume that was deflected into the dewatering wells is being diverted around the barrier to the recharge side.

Respectfully submitted,

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BIBLIOGRAPHY

D'APPOLONIA

BIBLIOGRAPHY

Arndt, M., 1976, Hydrologic Concerns Related to WES-Project, Memorandum to Irwin Glassman.

Baski, H. A., 1976, Review Report to Dr. William McNeill Comparing Various Dewatering and Recharge Systems.

Black and Veach Consulting Engineers, 1978, "Concept Design analysis, Liquid Waste Disposal Facility, Rocky Mountain Arsenal," unpublished report to the Army Corps of Engineers.

Bouwer, Herman, 1978, "Groundwater Hydrology," McGraw-Hill, New York, 480 pp.

Byrne, J. P. col., 1977, "Evaluation of the Recharge Component of the Pilot Containment System," unpublished report.

Denver Pump Co., Inc., 1977, "Pilot Containment System-Bentonite Slurry Barrier-Recharge System Evaluation," unpublished report to Mr. B. M. Arndt, U. S. Army.

Glassman, Irwin, M., 1977, "Installation Restoration Program-Pilot Containment-Recharge System Test Plan," unpublished report to Chief, Engineering Div., U. S. Army Waterways Experiment Station, Corps of Engineers.

Glover, Robert E., 1974, "Transient Groundwater Hydraulics," Colorado State University, Fort Collins, Colorado.

Kolmer, J. R., and G. A. Anderson, 1977a, Installation Restoration of Rocky Mountain Arsenal, Part 1 - Pilot Containment Operations, Draft Environmental Impact Statement, Office of the Project Manager for Chemical Demilitarization and Installation Restoration, U. S. Army.

Kolmer, J. R. and G. A. Anderson, 1977b, Installation Restoration of Rocky Mountain Arsenal, Part 1 - Pilot Containment Operations, Final Environmental Impact Statement, Office of the Project Manager for Chemical Demilitarization and Installation Restoration, U. S. Army.

Konikow, L. F., 1975, Hydrogeologic Maps of the Alluvial Aquifer in and Adjacent to the Rocky Mountain Arsenal, U. S. Geol. Survey open-file report 74-342. 8432-1021

Krimmer, M. W., 1979, "Groundwater Quality, North Boundary," unpublished basic data.

Lambe, W. T., and R. W. Whitman, 1969, "Soil Mechanics," John C. Wiley and Sons, Inc., New York, 553 pp.

BIBLIOGRAPHY
(Continued)

McNeill, W., 1977, Comment on Battelle Report, Dept. of Army, Rocky Mountain Arsenal.

Miller, S. P., 1977, Visit to Rocky Mountain Arsenal 24-25 January, 1977, Memorandum for Record, U. S. Army Corps of Engineers, Waterways Experiment Station.

Miller, S. P., undated, Grain Size Data, Filter and Screen Calculations, unpublished basic data.

Mitchell, G. B., 1976, "Interim Containment System, Rocky Mountain Arsenal, Memorandum for Record, Waterways Experiment Station," U. S. Army Corps of Engineers.

Petri, Lester R. and Rex O. Smith, 1956, "Investigation of the Quality of Ground Water in the Vicinity of Derby, Colorado," U. S. Geol. Survey open-file Administrative Report.

Reynolds, J. W., 1975, "Rocky Mountain Arsenal Off-Post Containment Control Plan," U. S. Army Armament Command, Rocky Mountain Arsenal.

Robson, S. G., 1976, "Digital Model Study of Ground Water Contamination by DIISOPROPYLMETHYLPHOSPHONATE (DIMP) Rocky Mountain Arsenal near Denver, Colorado," Final Report to U. S. Dept. of the Army, Rocky Mountain Arsenal, U. S. Geol. Survey Administrative Report.

Thomas, T. J., S. Smith, and H. Eagon, 1977, "Study of Alternatives for Ground Water Pollution Control at the North Boundary of Rocky Mountain Arsenal," Report to Project Manager for Chemical Demilitarization and Installation Restoration, Department of the Army, Battelle Columbus Laboratories and Moody and Associates.

U. S. Army Corps of Engineers, 1961, Program for Restoration of Surface Aquifer Rocky Mountain Arsenal Denver, Colorado.

U. S. Army, Rocky Mountain Arsenal, 1976, 360° Water Monitoring Program, unpublished basic data.

U. S. Army, Rocky Mountain Arsenal, 1977a, Boring Location North Area, unpublished basic data.

_____, 1977b, Water Chemistry Data, unpublished basic data.

_____, 1977c, Pilot Containment System - Phase I Plates, unpublished basic data.

_____, 1978a, Miscellaneous Water Well Data, June 1978 through May 1979, unpublished basic data.

BIBLIOGRAPHY
(Continued)

- ____, 1978b, Water Chemistry Data, unpublished basic data.
- ____, 1979a, Pilot Containment System Updates Through April 30, 1979, unpublished basic data.
- ____, 1979b, update - Calgon Plant Water Quality, unpublished basic data.
- ____, 1979c, update - Pilot Plant and Monitoring Well Water Level Data, 13 June 1979, unpublished basic data.
- ____, 1979d, Water Chemistry Data, unpublished basic data.
- ____, 1979e, Pilot Containment System Well Log Data, unpublished basic data.
- ____, undated a, Off-Post Water Level Data, unpublished basic data.
- ____, undated b, Observation Well Summary Report, unpublished basic data.
- ____, undated c, Monitoring Well Water Level Data through March, 1979, unpublished basic data.
- ____, undated d, Depth to Water and Bedrock for Recharge and Dewatering Wells, unpublished basic data.
- ____, undated e, Dewater and Recharge Well Data - Well Logs, unpublished basic data.
- ____, undated f, Off-Post Monitoring Well Data - Well Logs, unpublished basic data.
- ____, undated g, Map of Pilot Containment System Monitoring Wells, unpublished basic data.
- ____, undated h, Boring Logs for Wells North of Coordinate 193000 N., unpublished basic data.
- ____, undated i, Boring Logs Ax001-679, unpublished basic data.
- ____, undated j, Letter to Mr. Irwin Glassman, unpublished basic data.
- U. S. Army, Toxic and Hazardous Material Agency, 1979, Part II - Expanded North Boundary Containment Operations, Draft Environmental Impact Statement.
- Vispi, Mark A., 1978, Report of Finding, Rocky Mountain Arsenal Pumping Tests, U. S. Army Corps of Engineers Waterways Experiment Station.

TABLES

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TABLE 1
 PREDICTED DRAWDOWNS ⁽¹⁾
 AND ACTUAL DRAWDOWNS
 AFTER 10 DAYS OF OPERATION

WELL NO.	PREDICTED		ACTUAL	
	DRAWDOWN (ft)	FLOW RATE (gpm)	DRAWDOWN (ft)	AVERAGE FLOW RATE (gpm)
321	2.5	4	1.29	1.4
320	3.3	5	3.15	4.8
319	3.5	14	2.28	10.2
318	3.5	14	1.52	5.3
317	3.2	16	1.63	12.2
316	2.6	17	1.38	12.9

⁽¹⁾ Kolmer and Anderson, 1977.

TABLE 2
MODIFIED DESIGN PREDICTIONS OF
DRAWDOWN BASED ON ACTUAL PUMPING RATES
COMPARED WITH OBSERVED DRAWDOWNS

WELL NO.	ACTUAL PUMPING RATE (gpm)	MODIFIED DRAWDOWN ⁽¹⁾ PREDICTION		OBSERVED DRAWDOWN 10 days
		7 days	10 days	
321	1.4	1.3	1.6	1.29
320	4.8	2.3	2.6	3.15
319	10.2	3.9	4.3	2.28
318	5.3	2.1	2.5	1.52
317	12.2	2.1	2.5	1.63
316	12.9	2.4	2.7	1.38

(1) Prediction based on Theis equation using actual pumping rates.

TABLE 3
WELL SIMULATOR INPUT DATA
FOR 60 DAYS OF OPERATION

WELL NO.	CARTESIAN COORDINATES X Y	FLOW RATE (gpm)	OBSERVATION POINT RADIUS (1) (ft)	SATURATED THICKNESS (ft)	PERMEABILITY (gpd/ft ²)	TRANSMISSIVITY (gpd/ft)	STORAGE COEF.
321	-	1.5	2.5	3.0	1,500	4,500	.10
320	230	5.0	2.5	5.0	1,200	6,000	.10
319	462	6.0	2.5	3.0	4,000	12,000	.10
318	690	11.0	2.5	8.0	3,000	24,000	.10
317	925	19.5	2.5	12.0	2,500	30,000	.10
316	1153	20.0	2.5	7.0	3,400	23,975	.10
3214	-	1.5	2.5	3.0	1,500	4,500	.10
3204	230	5.0	2.5	5.0	1,200	6,000	.10
3194	462	6.0	2.5	3.0	4,000	12,000	.10
3184	690	11.0	2.5	8.0	3,000	24,000	.10
3174	925	19.5	2.5	12.0	2,500	30,000	.10
3164	1153	20.0	2.5	7.0	3,400	23,975	.10
OP 1	500 -100	-	-	8.0	3,000	24,000	.10
OP 2	500 -250	-	-	8.0	3,000	24,000	.10
OP 3	500 -500	-	-	8.0	3,000	24,000	.10
OP 4	500 -1000	-	-	8.0	3,000	24,000	.10
OP 5	500 -2500	-	-	8.0	3,000	24,000	.10
OP 6	500 -3000	-	-	8.0	3,000	24,000	.10
OP 7	500 -3500	-	-	8.0	3,000	24,000	.10
OP 8	500 -4000	-	-	8.0	3,000	24,000	.10
OP 9	500 -5000	-	-	8.0	3,000	24,000	.10

(1) Observation radius is at closest observation point to dewatering well and is taken as the water level in the pumping well.

OP 1 - Observation Point No. 1 (theoretical locations).

See Figure 11 for location of wells and coordinate axes.

TABLE 4
COMPARISON OF ACTUAL
AND PREDICTED DRAWDOWNS
AFTER 60 DAYS OF OPERATION

WELL NO.	PREDICTED DRAWDOWN (ft)	ACTUAL DRAWDOWN (ft)
321	1.9	1.78
320	2.9	3.41 ⁽¹⁾
319	2.7	2.65
318	2.6	2.97
317	2.8	3.15
316	2.9	2.74
OP 1	2.1	_(2)
OP 2	1.7	_(2)
OP 3	1.3	_(2)
OP 4	0.7	_(2)
OP 5	0.1	_(2)
OP 6	0.1	_(2)
OP 7	0.0	_(2)
OP 8	0.0	_(2)
OP 9	0.0	_(2)

(1) Excess drawdown may be due to well losses.

(2) Actual drawdown not quantified due to fluctuations in groundwater levels.

FIGURES

D'APPOLONIA

DRAWN BY S.L.T. CHECKED BY F.R.H. 1-29-77 DRAWING NUMBER 9-389-A3
 7-5-79 APPROVED BY JCM 7-29-77

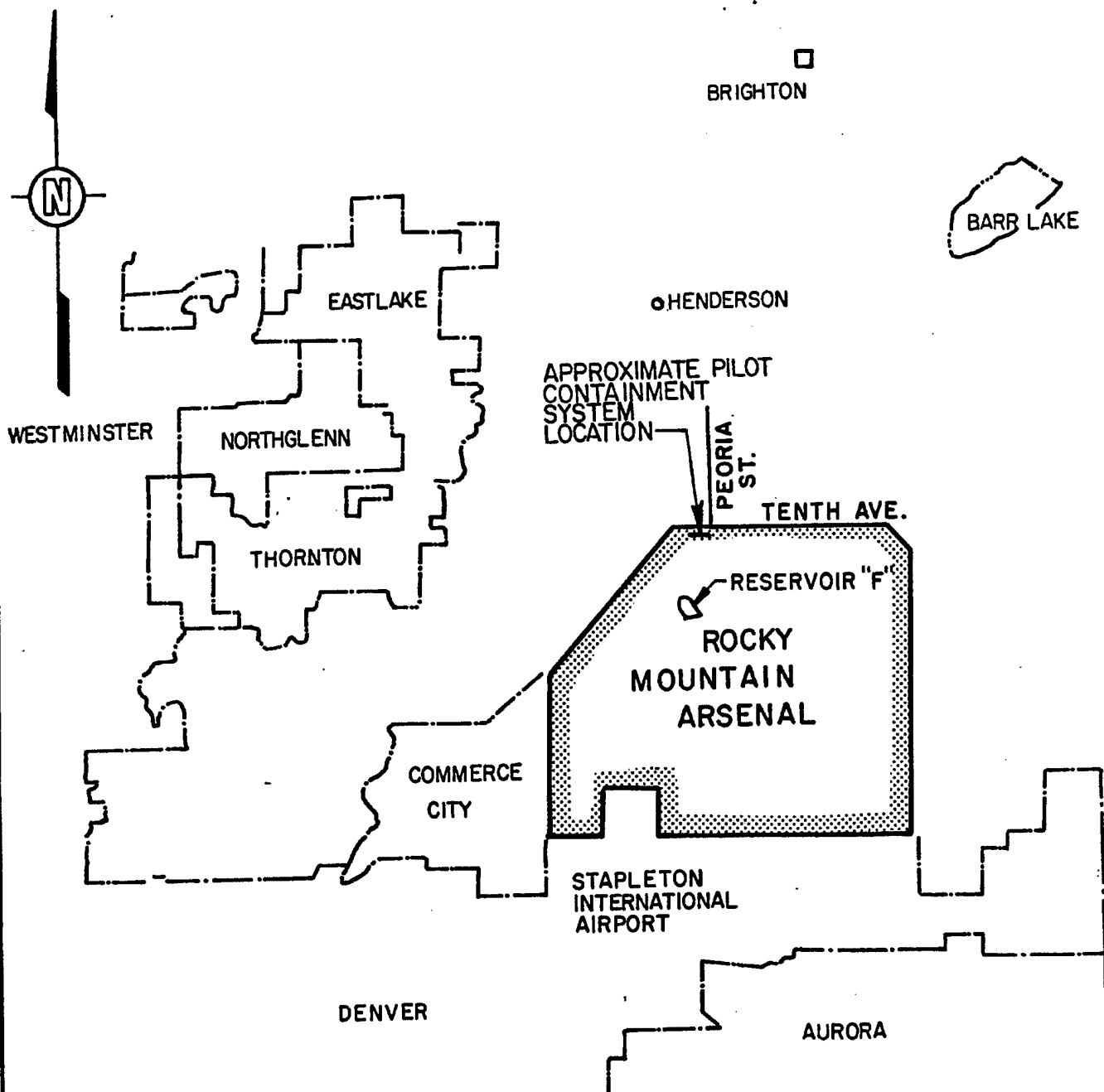


FIGURE 1
 VICINITY MAP

NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
 ROCKY MOUNTAIN ARSENAL
 DENVER, COLORADO

PREPARED FOR
 BATTELLE COLUMBUS LABORATORIES
 COLUMBUS, OHIO

D'APPOLONIA

REFERENCE:
 KOLMER AND ANDERSON, 1977B.

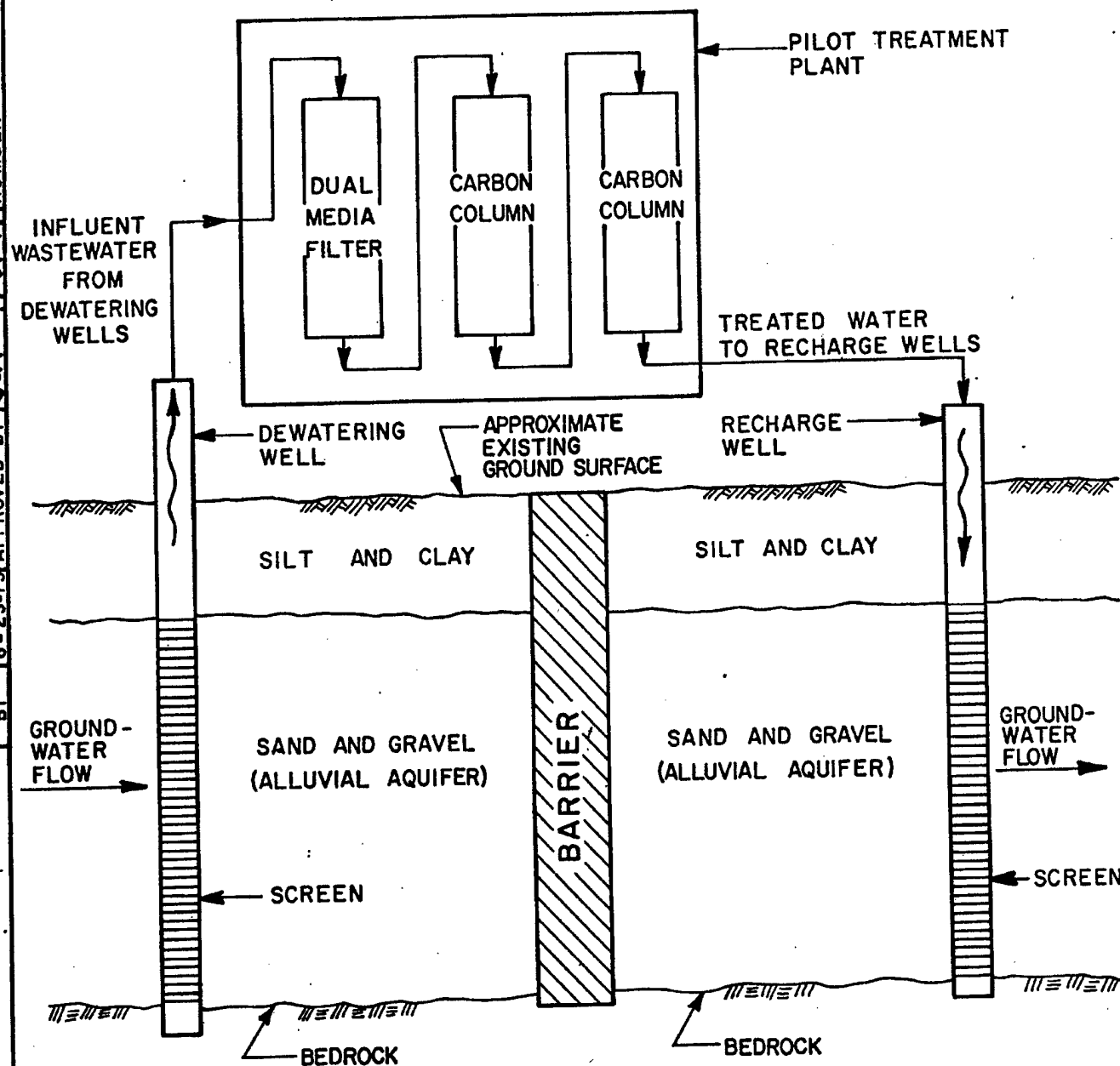


FIGURE 2

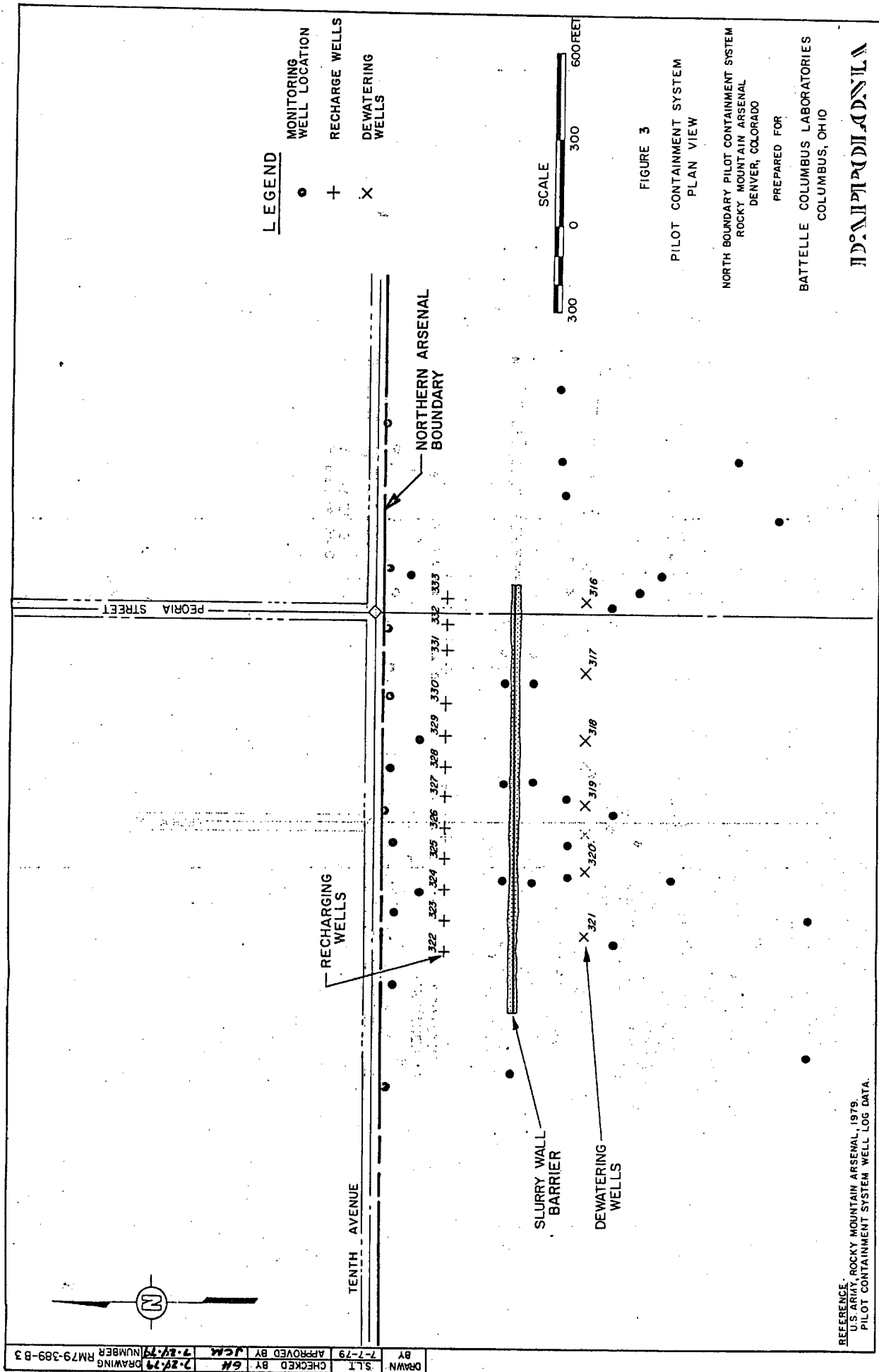
SCHEMATIC DIAGRAM OF
 PILOT CONTAINMENT SYSTEM

NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
 ROCKY MOUNTAIN ARSENAL
 DENVER, COLORADO

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
 COLUMBUS, OHIO

D'APPOLONIA



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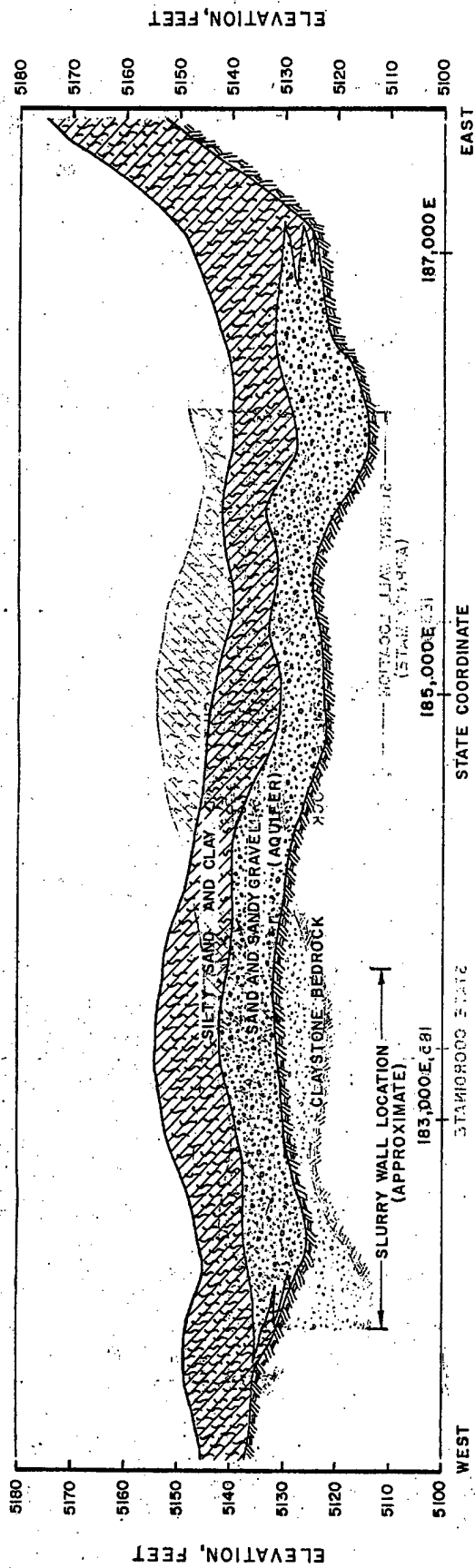


FIGURE 5
DIAGRAMATIC GEOLOGIC CROSS-SECTION
IN THE VICINITY OF THE
NORTH ARSENAL BOUNDARY



NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

PREPARED FOR
BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

D'APPOLONIA

REFERENCE:
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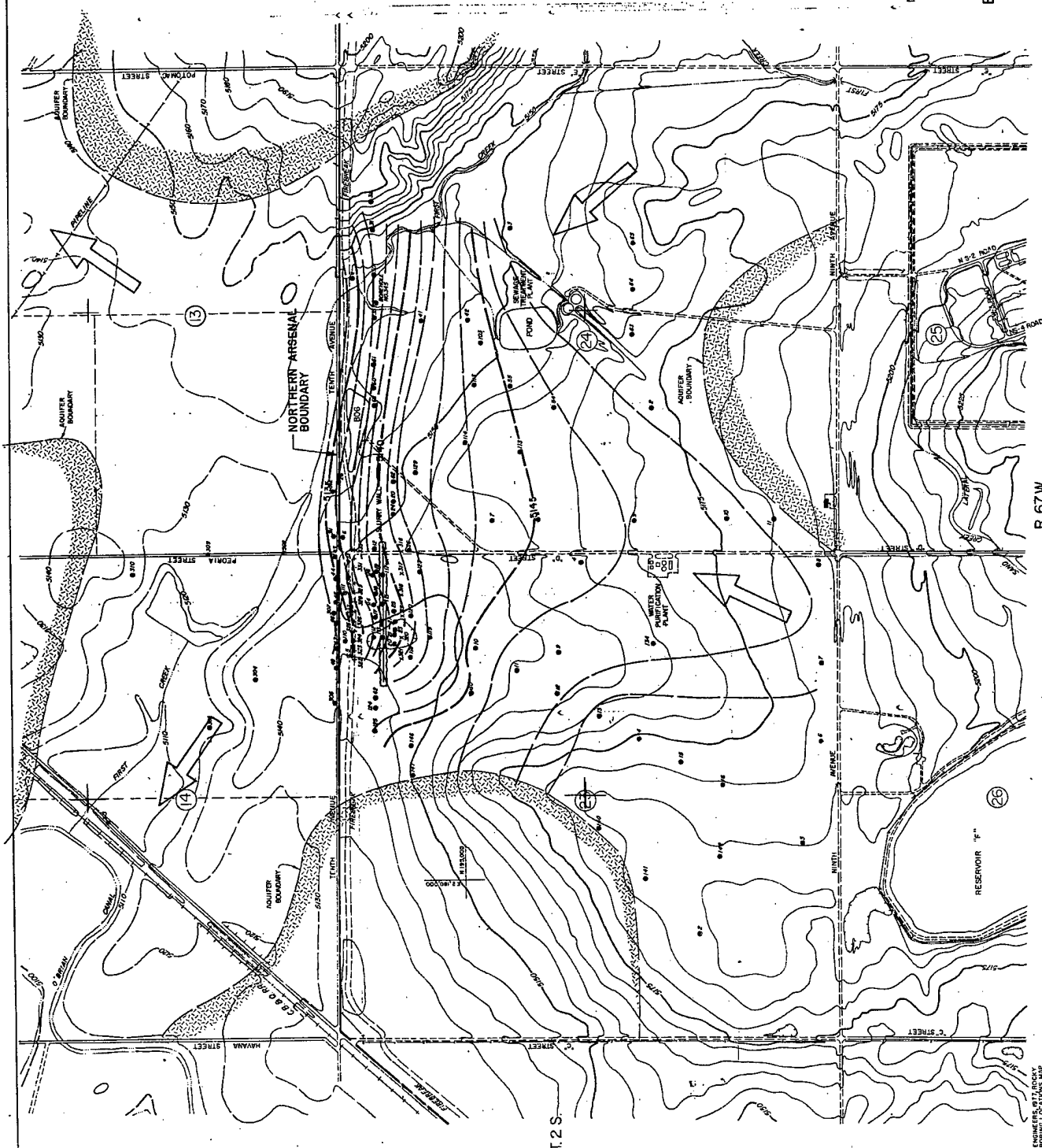


FIGURE 6
POTENTIOMETRIC SURFACE MAP
PRESYSTEM

NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

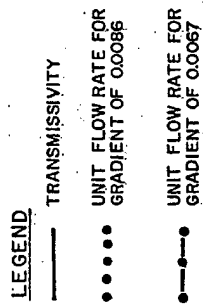
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REFERENCE:
1. U.S. ARMY CORPS OF ENGINEERS, WTI ROCKY MOUNTAIN ARSENAL BRIDGE LOCATION MAP, 1:25,000 SCALE, 1965.
2. 7.5 MINUTE SERIES U.S.G.E. TOPOGRAPHIC MAPS, 1:25,000 SCALE, 1965.
DATE 1985

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6-30-79	APPROVED BY	JCM	7/1/79
NUMBER	7/24/79	DRAWING RM79-389-E1	

AQUIFER TRANSMISSIVITY AND
FLOW RATES ACROSS NORTHERN
ARSENAL BOUNDARY

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

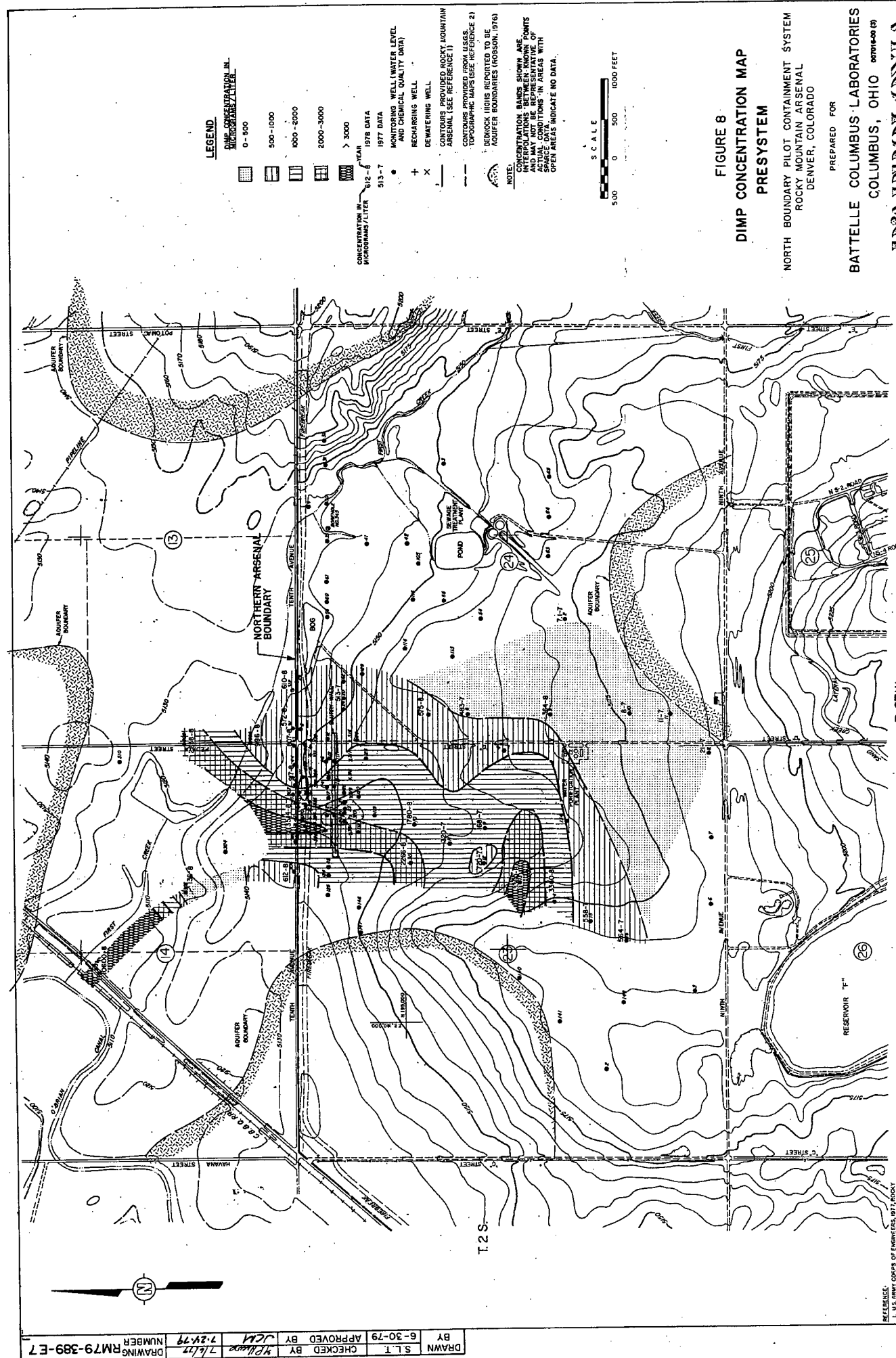
D'APPOLONIA

NOTES: 1. TRANSMISSIVITY = $K_{\text{sand}} \bullet M_{\text{sand}} + K_{\text{gravel}} \bullet M_{\text{gravel}}$
WHERE K = PERMEABILITY
 M = SATURATED THICKNESS UNDER AVERAGE CONDITIONS.

IN THE VEST INTERESTS OF THE ELECTRIC

2. TOTAL FLOW IS EQUAL TO THE AREA UNDER A SPECIFIC FLOW RATE CURVE.

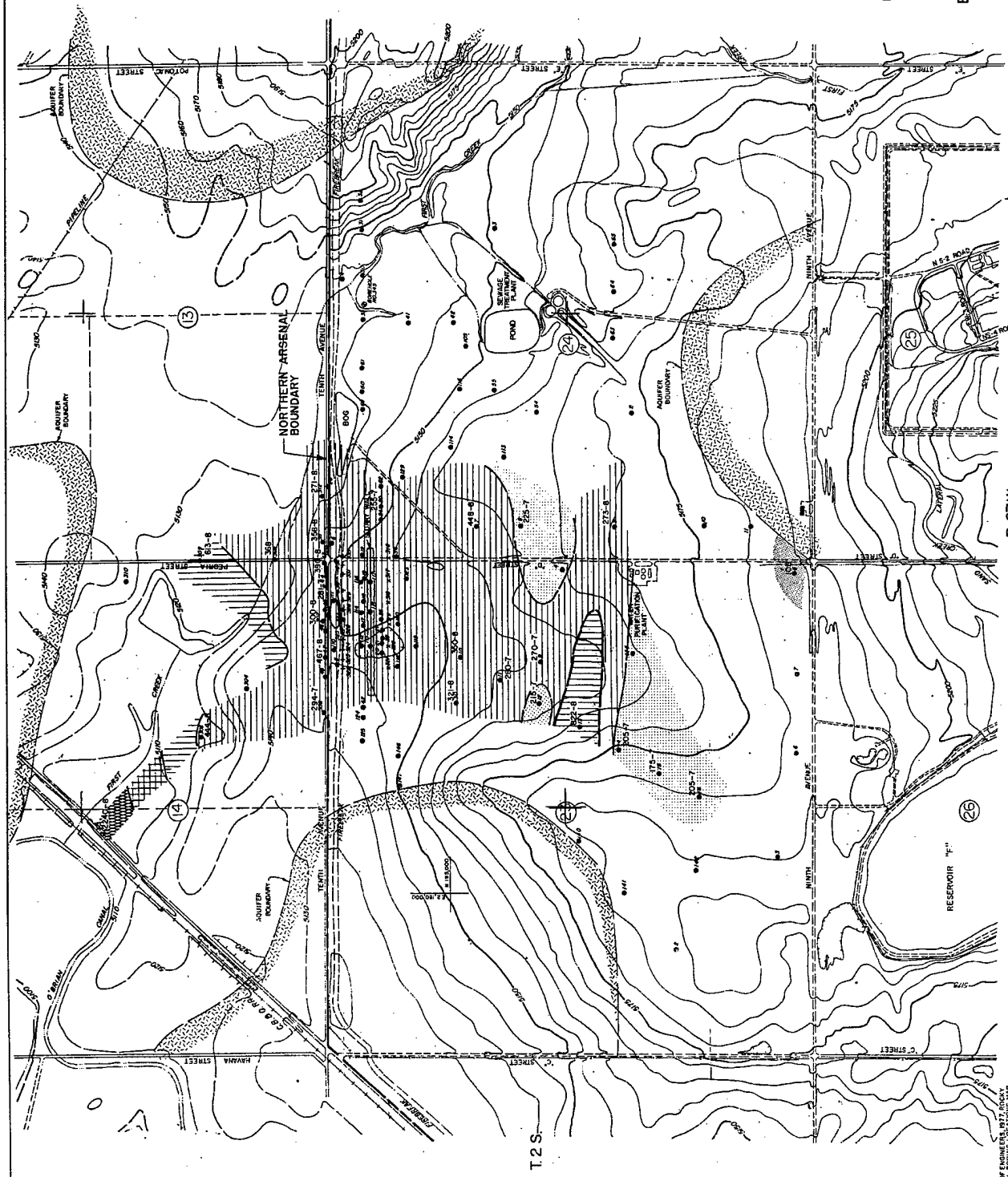
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R. 67W.

REFERENCE:
1. U.S. ARMY CORPS OF ENGINEERS, 1977, ROCKY MOUNTAIN ARSENAL, DENVER, COLORADO, 7.5 MINUTE SERIES USGS TOPOGRAPHIC MAPS OF THE NORTH AREA, DENVER, COLORADO.
2. 7.5 MINUTE SERIES USGS TOPOGRAPHIC MAPS OF THE NORTH AREA, DENVER, COLORADO, DATE 1965, SCALE 1:125,000.

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DRAWING	NUMBER	RM79-389-E7		



LEGEND

- CHLORIDE CONCENTRATION IN MILLIGRAMS/LITER
- 0 - 250
 - 250 - 500
 - 500 - 1000
 - 1000 - 2000
 - > 2000
- CONCENTRATION IN MILLIGRAMS/LITER
- 250-6
 - 225-7
 - 1978 DATA
 - 1977 DATA
 - MONITORING WELL WATER LEVEL AND CHEMICAL QUALITY DATA
 - RECHARGING WELL
 - DEWATERING WELL
 - CONTOURS PROVIDED FROM USGS TOPOGRAPHIC MAPS (SCALE NO REFERENCE 21)
 - ROCKY MOUNTAIN ARSENAL (SCALE NO REFERENCE 21)
 - ACQUIFER BOUNDARIES (MORISON, 1976)
- NOTE: CONCENTRATION BANDS SHOWN ARE INTERPOLATIONS BETWEEN KNOWN POINTS. ACTUAL CONCENTRATIONS MAY VARY. ACTUAL CONCENTRATIONS IN AREAS WITH OPEN AREAS INDICATE NO DATA.



FIGURE 10
CHLORIDE CONCENTRATION MAP
PRESYSTEM

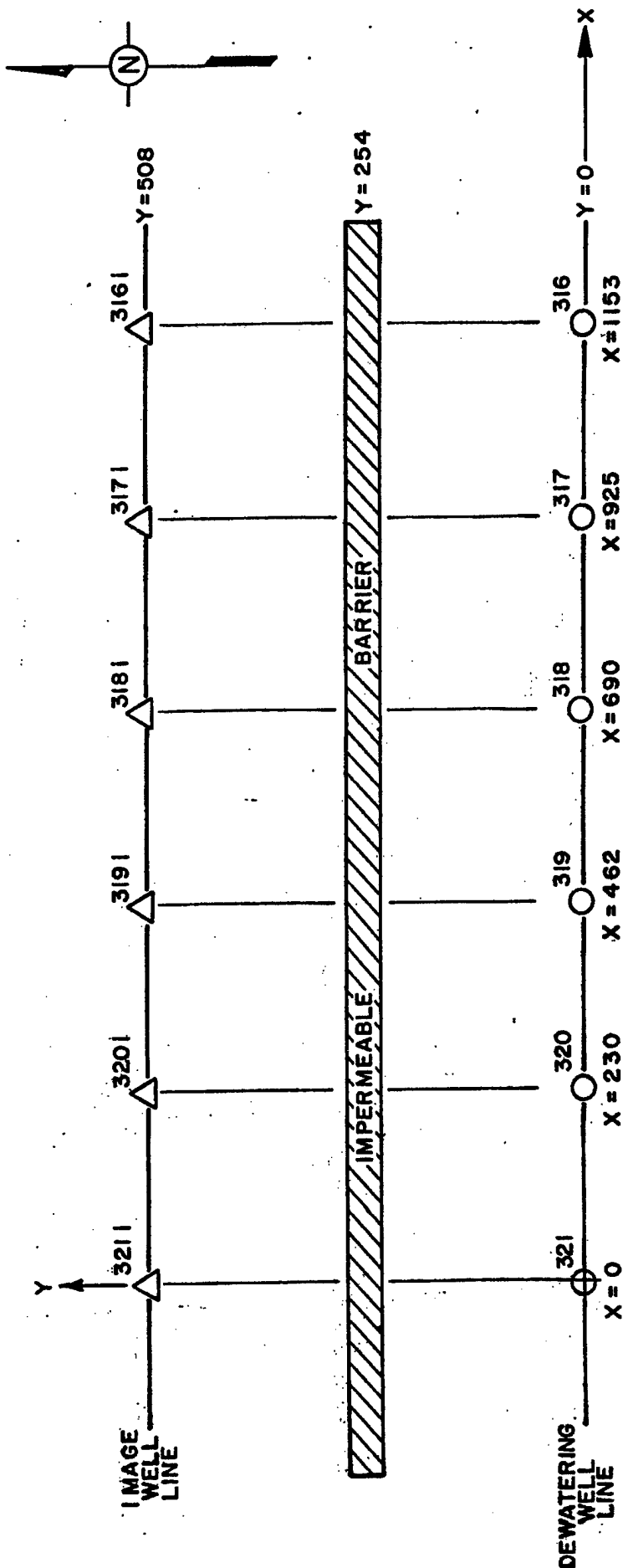
NORTH BOUNDARY PILOT CONTAMINANT SYSTEM
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

PREPARED FOR
BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO 43060-0001
INDIANAPOLIS

R. 67W.

REFERENCE:
1. U.S. ARMY CORPS OF ENGINEERS, 1977, ROCKY MOUNTAIN ARSENAL, DENVER, COLORADO, 1:25,000 SCALE, 1977.
2. 7.5-MINUTE SERIES U.S. TOPOGRAPHIC MAPS OF THE NORTHWESTERN QUARTER, COLORADO, DATE 1963, SCALE 1:25,000.

DRAWN	SLT	CHECKED BY	APPROVED BY	BY
6-30-79	7/2/79	7/2/79	7/2/79	7/2/79
DRAWING NUMBER RM79-389-E6				



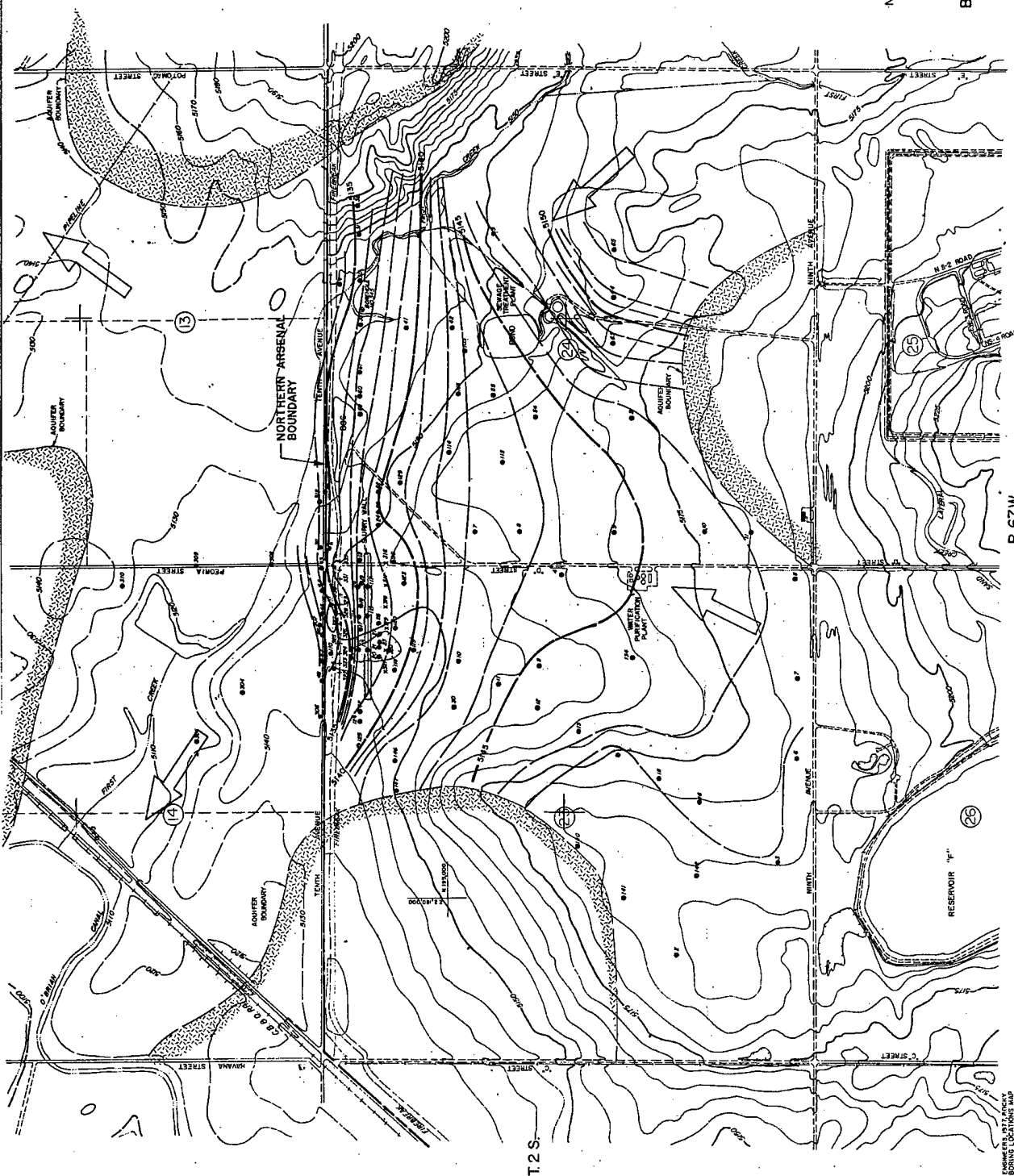
NOTE: BARRIER WIDTH NOT TO SCALE



FIGURE 11

DEWATERING SIMULATION
WELL LOCATION
NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO
PREPARED FOR
BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

D'APPOLONIA



- LEGEND**
- MONITORING WELL (WATER LEVEL AND CHEMICAL QUALITY DATA)
 - + RECHARGING WELL
 - x DEWATERING WELL
 - APPROXIMATE POTENTIOMETRIC SURFACE (CONTOUR DATUM MEAN SEA LEVEL)
 - DIRECTION OF GROUNDWATER FLOW (ROBSON, 1976)
 - CONTOUR PROVIDED FROM U.S.G.S. TOPOGRAPHIC MAPS (SEE REFERENCE 2)
 - REDUCED HIGHS REPORTED TO BE AQUIFER BOUNDARIES (ROBSON, 1976)
 - NOTE: OPEN AREAS INDICATE NO DATA.

SCALE

0 500 1000 FEET

POTENTIOMETRIC CONTOUR INTERVAL: 1 FOOT

FIGURE 12

POTENTIOMETRIC SURFACE MAP

SEPTEMBER - OCTOBER, 1978

NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

PREPARED FOR
BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

DAMPOLONIA

00716-00 (9)

DRAWN	S.L.T.	CHECKED BY	APPROVED BY	BY	6-30-79
NUMBER	7/6/79	25879	25879	25879	25879
DRAWING	RM79-389-E2				

REFERENCE:

1. U.S. ARMY CORPS OF ENGINEERS, 9775 PAVAN, DENVER, COLORADO, 80231, 1978, "POTENTIOMETRIC SURFACE MAP OF THE NORTH AREA, DENVER, COLORADO."
2. U.S. ARMY CORPS OF ENGINEERS, 9775 PAVAN, DENVER, COLORADO, 80231, 1978, "POTENTIOMETRIC SURFACE MAP OF THE NORTH AREA, DENVER, COLORADO."

DATE: 1985 SCALE: 1" = 2400'

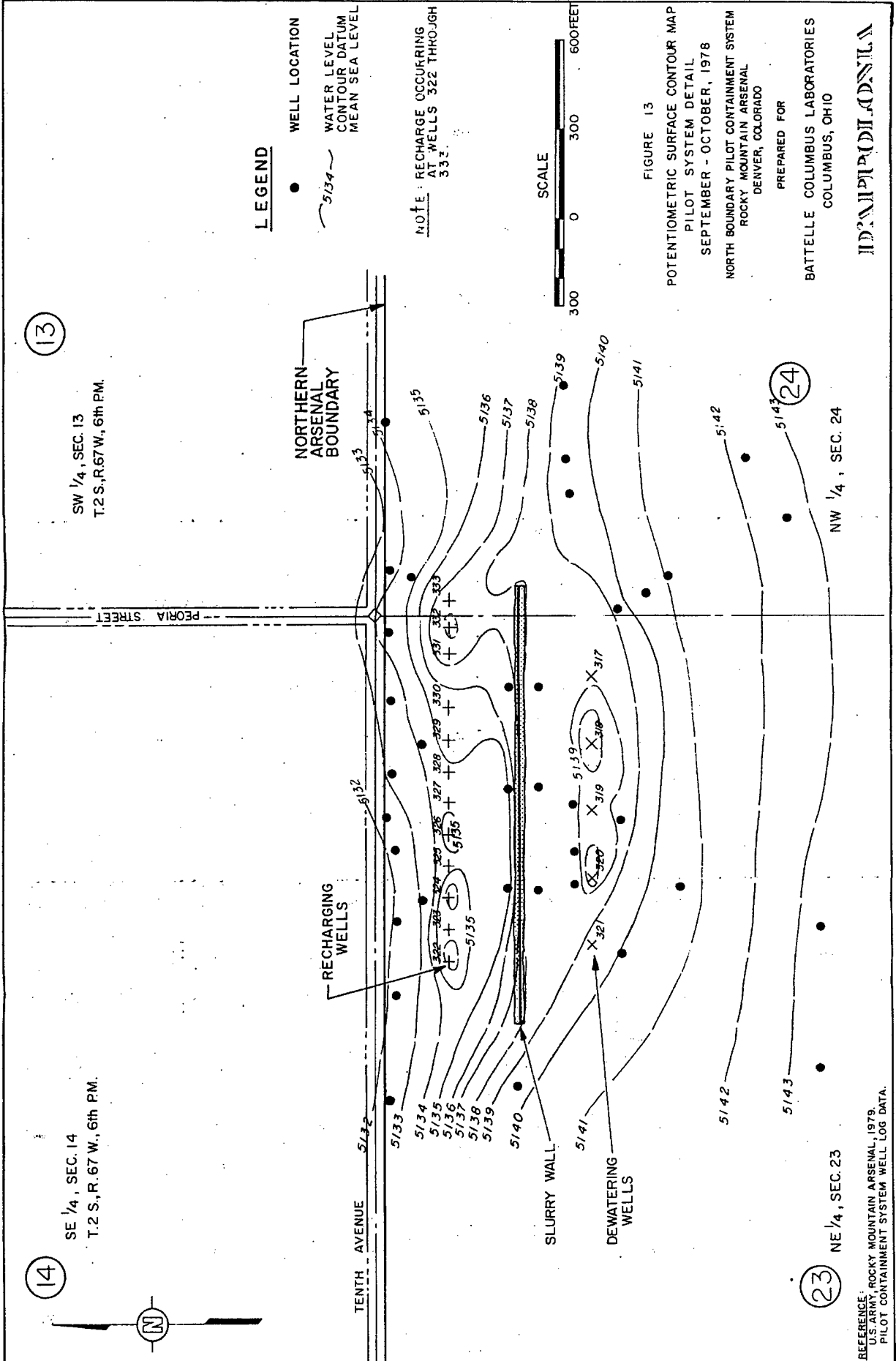
DRAWN BY S.L.T. 7-25-79
 CHECKED BY G.R.H. 7-25-79
 APPROVED BY J.C.M. 7-25-79
 DRAWING NUMBER RM79-389-B6

14

SE 1/4, SEC. 14
 T.2 S., R. 67 W., 6th PM.

13

SW 1/4, SEC. 13
 T.2 S., R. 67 W., 6th PM.



LEGEND

- WELL LOCATION
- 5134 — WATER LEVEL CONTOUR DATUM MEAN SEA LEVEL

NOTE: RECHARGE OCCURRING
 AT WELLS 322 THROUGH
 332.

SCALE



FIGURE 13

POTENTIOMETRIC SURFACE CONTOUR MAP
 PILOT SYSTEM DETAIL
 SEPTEMBER - OCTOBER, 1978
 NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
 ROCKY MOUNTAIN ARSENAL
 DENVER, COLORADO

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
 COLUMBUS, OHIO

IDENTIFICATION

23

NE 1/4, SEC. 23

24

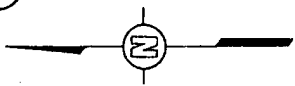
NW 1/4, SEC. 24

REFERENCE:
 U.S. ARMY, ROCKY MOUNTAIN ARSENAL, 1978.
 PILOT CONTAINMENT SYSTEM WELL LOG DATA.

DRAWN	S.L.T.	CHECKED BY	G.R.H.	7-25-79	NUMBER	RM79-389-B5
BY	7-7-79	APPROVED BY	J.C.H.	7-25-79		

14

SE 1/4, SEC. 14
T.2 S., R. 67 W., 6th PM.



13

SW 1/4, SEC. 13
T.2 S., R. 67 W., 6th PM.

LEGEND

- WELL LOCATION
- ~5134~ WATER LEVEL CONTOUR DATUM MEAN SEA LEVEL

NOTE: RECHARGE OCCURRING AT WELLS 331, 332 AND 333 ONLY.

SCALE



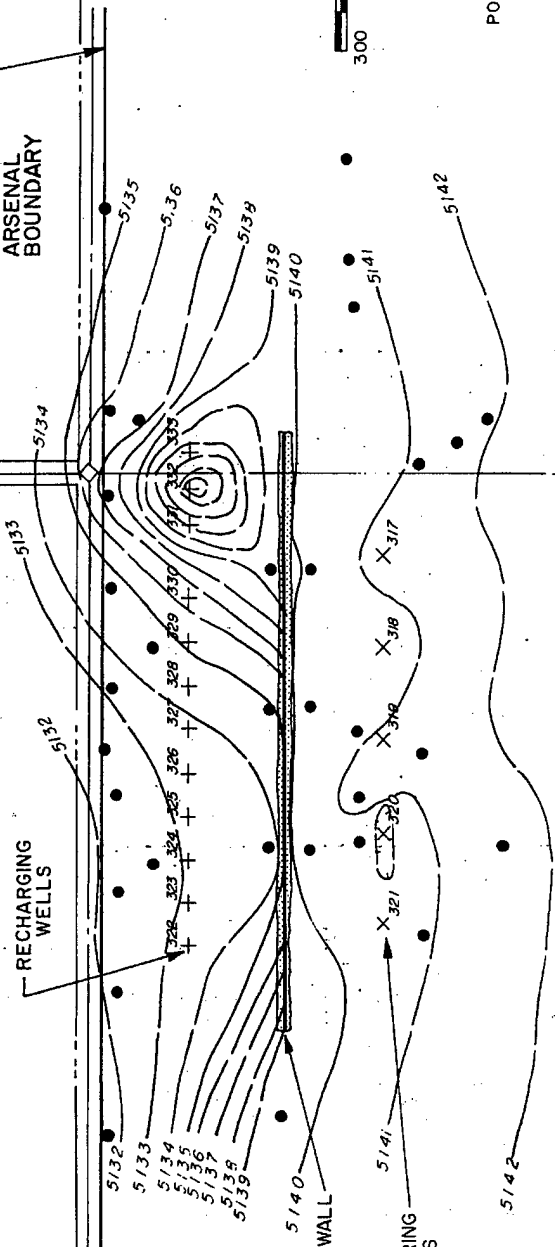
NORTHERN ARSENAL BOUNDARY

RECHARGING WELLS

TENTH AVENUE

SLURRY WALL

DEWATERING WELLS



23

NE 1/4, SEC. 23

24

NW 1/4, SEC. 24

REFERENCE:
U.S. ARMY, ROCKY MOUNTAIN ARSENAL, 1979.
PILOT CONTAINMENT SYSTEM WELL LOG DATA.

FIGURE 14

POTENTIOMETRIC SURFACE CONTOUR MAP
PILOT SYSTEM DETAIL
MARCH, 1979

NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

IDENTIFICATION

DRAWN BY: S.L.T. 7-5-79
 CHECKED BY: G.H. 7-5-79
 APPROVED BY: J.M. 7-5-79
 DRAWING NUMBER: RM79-389-82

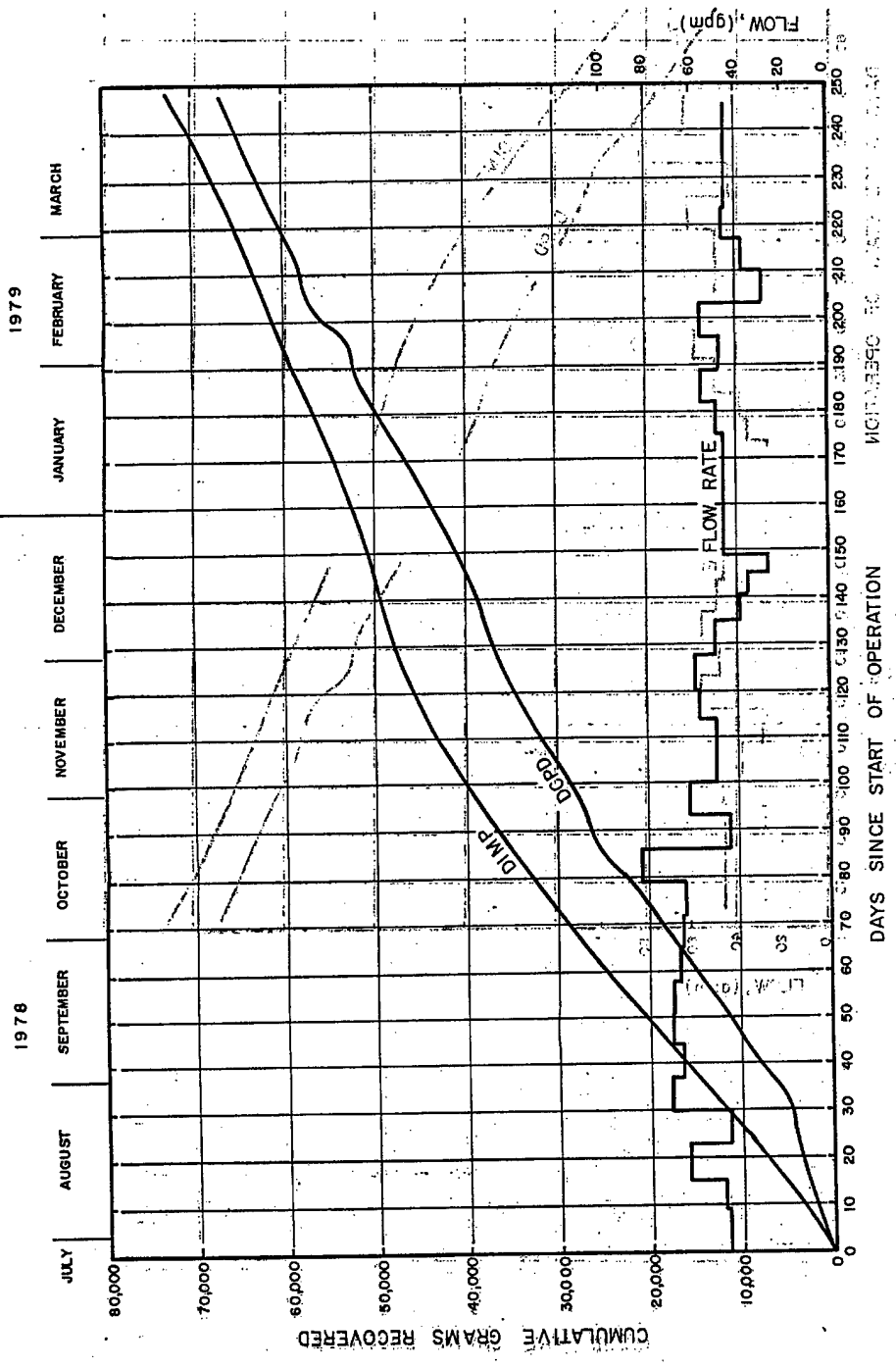
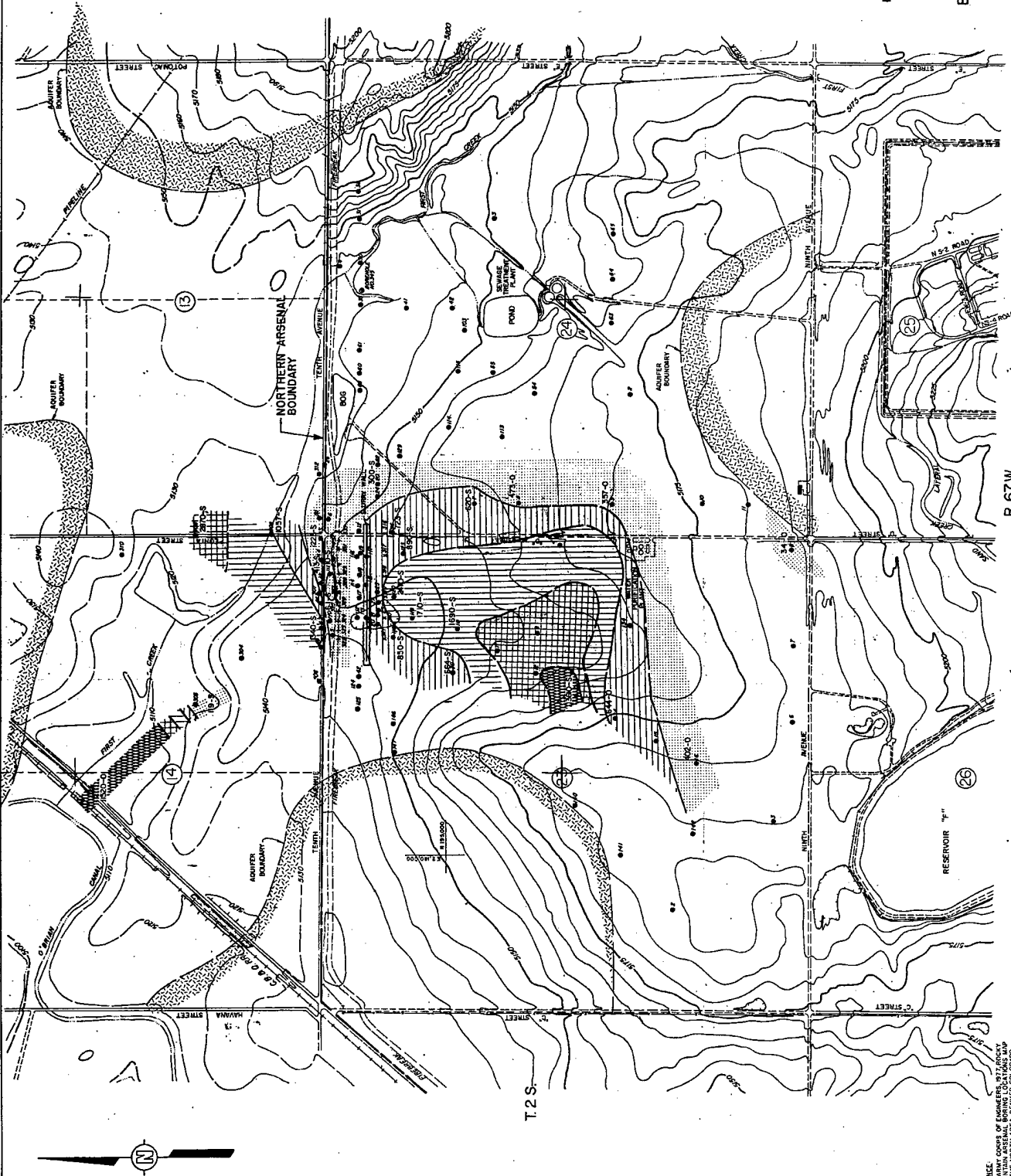


FIGURE 15
 CUMULATIVE RECOVERY
 FLOW RATE GRAPHS

NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
 ROCKY MOUNTAIN ARSENAL
 DENVER, COLORADO
 PREPARED FOR
 BATTELLE COLUMBUS LABORATORIES
 COLUMBUS, OHIO
IDAEPOLONIA



LEGEND

DIMP CONCENTRATION IN MONITORING WELL

0-500
 500-1000
 1000-2000
 2000-3000
 > 3000

SEPTEMBER DATA
 2470-S
 473-O

OCTOBER DATA
 MONITORING WELL (WATER LEVEL AND CHEMICAL QUALITY DATA)

RECHARGING WELL
 DEWATERING WELL

TOPOGRAPHIC MAP
 2.5 MINUTE SERIES U.S. GEOLOGICAL SURVEY
 1:25,000 SCALE

ROCKY MOUNTAIN ARSENAL
 1:25,000 SCALE

NOTE
 CONCENTRATION RANGES SHOWN ARE OBSERVATIONS FROM MONITORING WELLS AND MAY NOT BE REPRESENTATIVE OF ALL AREAS. CONCENTRATIONS IN AREAS WITH BLANK AREAS INDICATE NO DATA.

SCALE

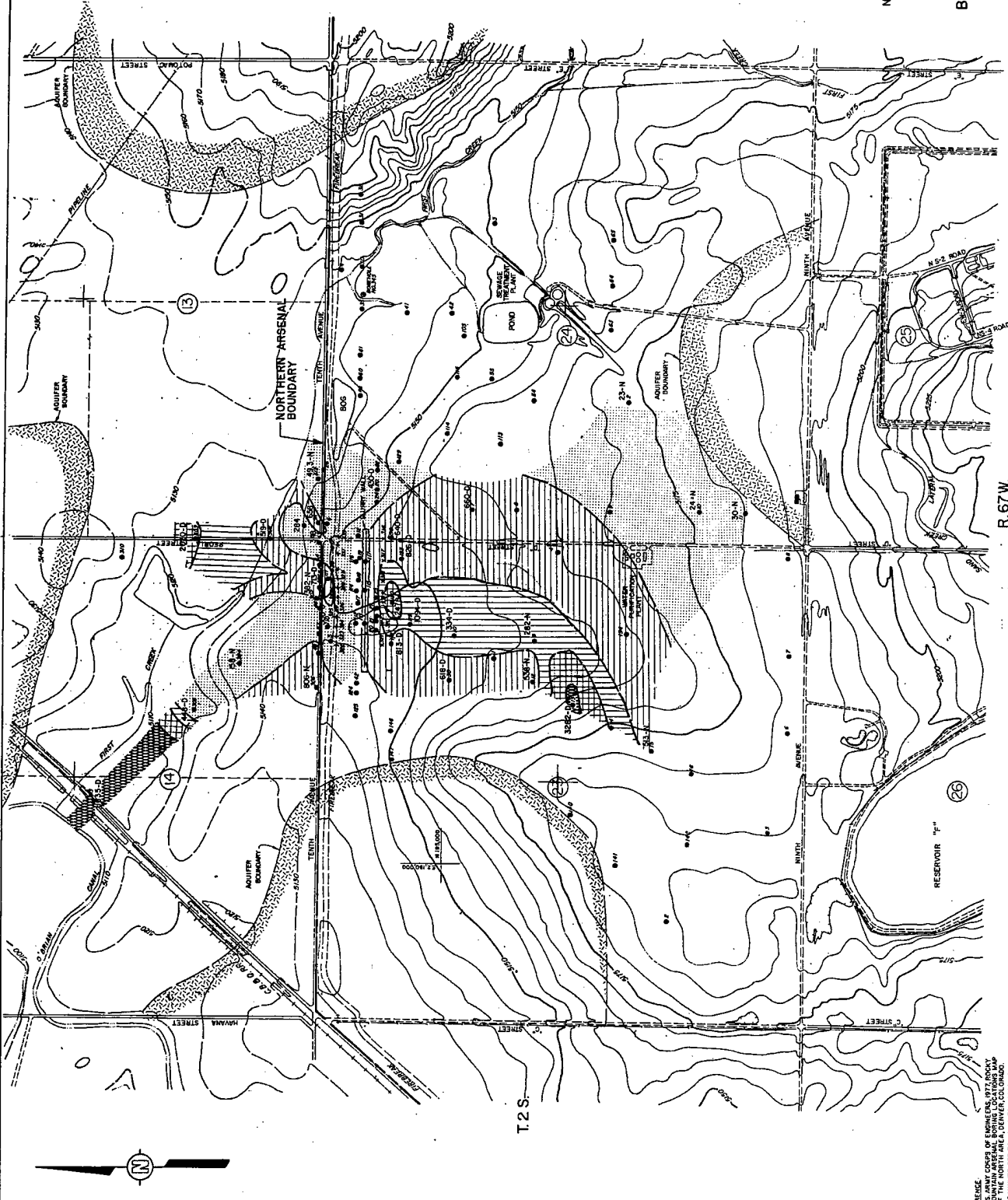
0 500 1000 FEET

FIGURE 16
DIMP CONCENTRATION MAP
SEPTEMBER-OCTOBER, 1978
 NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
 ROCKY MOUNTAIN ARSENAL
 DENVER, COLORADO

PREPARED FOR
BATTELLE COLUMBUS LABORATORIES
 COLUMBUS, OHIO

IDENTIFICATION ONLY

REFERENCE
 1. U.S. ARMY CORPS OF ENGINEERS, 917 ROCKY MOUNTAIN ARSENAL BORING LOCATIONS MAP, 1:25,000 SCALE, 1978
 2. 2.5 MINUTE SERIES U.S. GEOLOGICAL SURVEY, 1:25,000 SCALE, 1978



REFERENCE

1. BATTALION OF ENGINEERS, 1978, "NORTH BOUNDARY PILOT CONTAINMENT SYSTEM", ROCKY MOUNTAIN ARSENAL, DENVER, COLORADO.

2. 2.5 MINUTE, 7.5 MINUTE, 15 MINUTE, 30 MINUTE, 60 MINUTE, 120 MINUTE, 240 MINUTE, 480 MINUTE, 960 MINUTE, 1920 MINUTE, 3840 MINUTE, 7680 MINUTE, 15360 MINUTE, 30720 MINUTE, 61440 MINUTE, 122880 MINUTE, 245760 MINUTE, 491520 MINUTE, 983040 MINUTE, 1966080 MINUTE, 3932160 MINUTE, 7864320 MINUTE, 15728640 MINUTE, 31457280 MINUTE, 62914560 MINUTE, 125829120 MINUTE, 251658240 MINUTE, 503316480 MINUTE, 1006632960 MINUTE, 2013265920 MINUTE, 4026531840 MINUTE, 8053063680 MINUTE, 16106127360 MINUTE, 32212254720 MINUTE, 64424509440 MINUTE, 128849018880 MINUTE, 257698037760 MINUTE, 515396075520 MINUTE, 1030792151040 MINUTE, 2061584302080 MINUTE, 4123168604160 MINUTE, 8246337208320 MINUTE, 16492674416640 MINUTE, 32985348833280 MINUTE, 65970697666560 MINUTE, 131941395333120 MINUTE, 263882790666240 MINUTE, 527765581332480 MINUTE, 1055531162664960 MINUTE, 2111062325329920 MINUTE, 4222124650659840 MINUTE, 8444249301319680 MINUTE, 16888498602639360 MINUTE, 33776997205278720 MINUTE, 67553994410557440 MINUTE, 135107988821114880 MINUTE, 270215977642229760 MINUTE, 540431955284459520 MINUTE, 1080863910568919040 MINUTE, 2161727821137838080 MINUTE, 4323455642275676160 MINUTE, 8646911284551352320 MINUTE, 17293822569102704640 MINUTE, 34587645138205409280 MINUTE, 69175290276410818560 MINUTE, 138350580552821637120 MINUTE, 276701161105643274240 MINUTE, 553402322211286548480 MINUTE, 1106804644422573096960 MINUTE, 2213609288845146193920 MINUTE, 4427218577690292387840 MINUTE, 8854437155380584775680 MINUTE, 17708874310761169551360 MINUTE, 35417748621522339102720 MINUTE, 70835497243044678205440 MINUTE, 141670994486089356410880 MINUTE, 283341988972178712821760 MINUTE, 566683977944357425643520 MINUTE, 1133367955888714851287040 MINUTE, 2266735911777429702574080 MINUTE, 4533471823554859405148160 MINUTE, 9066943647109718810296320 MINUTE, 18133887294219437620592640 MINUTE, 36267774588438875241185280 MINUTE, 72535549176877750482370560 MINUTE, 145071098353755500964741120 MINUTE, 290142196707511001929482240 MINUTE, 580284393415022003858964480 MINUTE, 1160568786830044007717928960 MINUTE, 2321137573660088015435857920 MINUTE, 4642275147320176030871715840 MINUTE, 9284550294640352061743431680 MINUTE, 18569100589280704123486863360 MINUTE, 37138201178561408246973726720 MINUTE, 74276402357122816493947453440 MINUTE, 148552804714245632987894906880 MINUTE, 297105609428491265975789813760 MINUTE, 594211218856982531951579627520 MINUTE, 1188422437713965063903159255040 MINUTE, 2376844875427930127806318510080 MINUTE, 4753689750855860255612637020160 MINUTE, 9507379501711720511225274040320 MINUTE, 19014759003423441022450548080640 MINUTE, 38029518006846882044901096161280 MINUTE, 76059036013693764089802192322560 MINUTE, 152118072027387528179604384645120 MINUTE, 304236144054775056359208769290240 MINUTE, 608472288109550112718417538580480 MINUTE, 1216944576219100225436835077160960 MINUTE, 2433889152438200450873670154321920 MINUTE, 4867778304876400901747340308643840 MINUTE, 9735556609752801803494680617287680 MINUTE, 19471113219505603606989361234575360 MINUTE, 38942226439011207213978722469150720 MINUTE, 77884452878022414427957444938301440 MINUTE, 155768905756044828855914889876602880 MINUTE, 311537811512089657711829779753205760 MINUTE, 623075623024179315423659559506411520 MINUTE, 1246151246048358630847319119012823040 MINUTE, 2492302492096717261694638238025646080 MINUTE, 4984604984193434523389276476051292160 MINUTE, 9969209968386869046778552952102584320 MINUTE, 19938419936773738093557105904205168640 MINUTE, 39876839873547476187114211808410337280 MINUTE, 79753679747094952374228423616820674560 MINUTE, 159507359494189904748456847233641349120 MINUTE, 319014718988379809496913694467282698240 MINUTE, 638029437976759618993827388934565396480 MINUTE, 1276058875953519237987654777869130792960 MINUTE, 2552117751907038475975309555738261585920 MINUTE, 5104235503814076951950619111476523171840 MINUTE, 10208471007628153903901238222953046343680 MINUTE, 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10704357695294699107937144770871213522870599680 MINUTE, 21408715390589398215874289541742427045741199360 MINUTE, 42817430781178796431748579083484854091482398720 MINUTE, 85634861562357592863497158166969708182964797440 MINUTE, 171269723124715185726994316333939416365929594880 MINUTE, 342539446249430371453988632667878832731859189760 MINUTE, 685078892498860742907977265335757665463718379520 MINUTE, 1370157784997721485815954530671515330927436759040 MINUTE, 2740315569995442971631909061343030661854873518080 MINUTE, 5480631139990885943263818122686061323709747036160 MINUTE, 10961262279981771886527636245372122647419494072320 MINUTE, 21922524559963543773055272490744245294838988144640 MINUTE, 43845049119927087546110544981488490589677976289280 MINUTE, 87690098239854175092221089962976981179355952578560 MINUTE, 175380196479708350184442179925953962358711905157120 MINUTE, 350760392959416700368884359851907924717423810314240 MINUTE, 701520785918833400737768719703815849434847620628480 MINUTE, 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MINUTE, 91949732451953331501500821629018551017124347331016130560 MINUTE, 183899464903906663003001643258037102034248694662032261120 MINUTE, 367798929807813326006003286516074204068497389324064522240 MINUTE, 735597859615626652012006573032148408136994778648129044480 MINUTE, 1471195719231253304024013146064296816273989557296258088960 MINUTE, 2942391438462506608048026292128593632547979114592516177920 MINUTE, 5884782876925013216096052584257187265095958229185032355840 MINUTE, 11769565753850026432192105168514374530191916458370064711680 MINUTE, 23539131507700052864384210337028749060383832916740129423360 MINUTE, 47078263015400105728768420674057498120767665833480258846720 MINUTE, 94156526030800211457536841348114996241535331666960517693440 MINUTE, 188313052061600422915073682696229992483070663333921035386880 MINUTE, 376626104123200845830147365392459984966141326667842070773760 MINUTE, 753252208246401691660294730784919969932282653335684141547520 MINUTE, 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 DRAWING RM79-389-E5 NUMBER 7-25-79

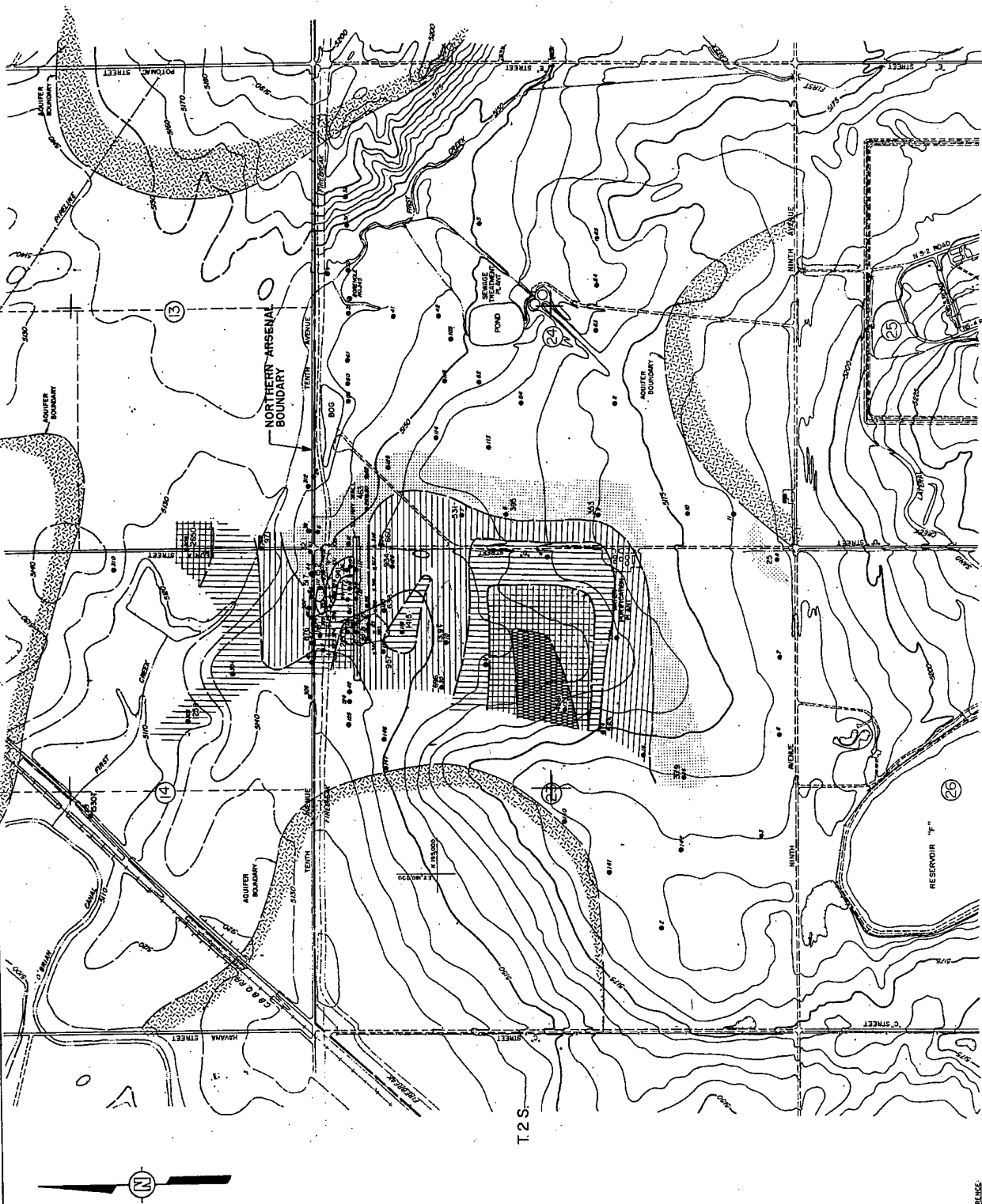
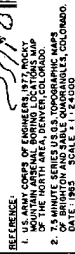


FIGURE 18
DIMP CONCENTRATION MAP
MARCH, 1979
 NORTH BOUNDARY PILOT CONTAMINATION SYSTEM
 ROCKY MOUNTAIN ARSENAL
 DENVER, COLORADO
 PREPARED FOR
 BATTELLE COLUMBUS LABORATORIES
 COLUMBUS, OHIO
 ID#NIPIDICNLA
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REFERENCE
 1. ARSENAL AREA OF INVESTIGATION
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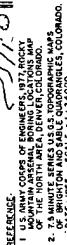


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BATTTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

INDIVIDUAL ONLY

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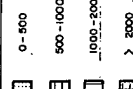
DRAWN	S.L.T.	CHECKED BY	<i>M. K. Singh</i>	7/6/79	DRAWING NUMBER
BY	6-30-79	APPROVED BY	JCM	7-25-79	RM79-389-E11



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LEGEND

OCPD CONCENTRATION IN MICROGRAMS/LITER



**MONITORING WELL (WATER LEVEL
AND CHEMICAL QUALITY DATA)**

RECHARGING WELL
DEWATERING WELL

NONE DETECTED

CONTAINS PROVIDED FROM U.S.G. ARSENAL (SEE REFERENCE I)

TOPOGRAPHIC MAPS (SEE REFERENCE)
BEDROCK HIGHS REPORTED TO BE

AQUIFER BOUNDARIES (ROBSON, 19

CONCENTRATION BANDS SHOWN ARE
POLYMERIZATION BETWEEN KNOWN POINTS

AY - NOT BE REPRESENTATIVE OF
ALL CONDITIONS IN AREAS WITH
THE DATA.

AREAS INDICATE NO DATA.

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500 1000 FEET

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RE 20

CONTRIBUTION MAP

H, 1979

DOT CONTAINMENT SYSTEM
CONTAIN ARSENAL

_____, COLORADO

ARE FOR

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FIGURE 20
DCPD CONCENTRATION MAP
MARCH, 1979

NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

PREPARED FOR

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

WINDMILL COTTAGE

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FIGURE 21
CHLORIDE CONCENTRATION MAP
MARCH, 1979

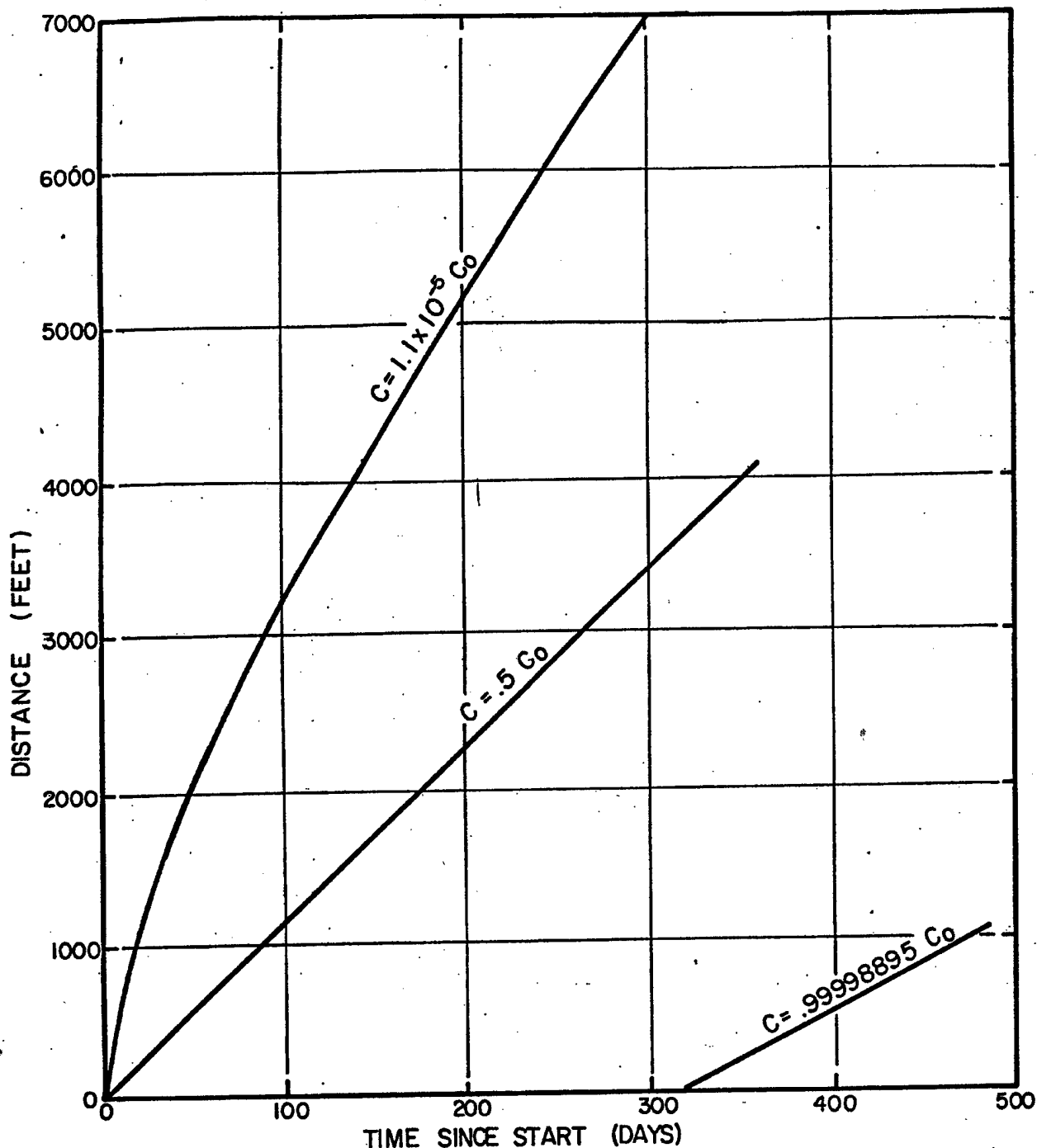
NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

PREPARED FOR
BATTTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

AND DELAY.

2007016-00 (12)

DRAWN BY	S.L.T.	CHECKED BY	APPROVED BY	DATE	DRAWING NUMBER
				7/25/79	RM79-389-E8



ASSUMPTIONS:

PERMEABILITY : 400 FT/DAY

EFFECTIVE POROSITY : 30%

GRADIENT : 0.0086

DISPERSION COEFFICIENT : 1150 FT²/DAY

EQUATION USED : $\frac{c}{c_0} = \frac{1}{2} \operatorname{erfc} \frac{(x - V_x t)}{2(D_L t)^{1/2}}$ (BOUWER, 1978)

WHERE:

c = CONCENTRATION AT POINT

c_0 = ORIGINAL CONCENTRATION

V_x = ACTUAL FLOW VELOCITY

D_L = DISPERSION COEFFICIENT

t = TIME SINCE MOVEMENT BEGAN

x = DISTANCE FROM ORIGIN

erfc = COMPLEMENTARY ERROR FUNCTION

FIGURE 22

THEORETICAL
EFFLUENT TIME-DISTANCE GRAPHS

NORTH BOUNDARY PILOT CONTAINMENT SYSTEM
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

PREPARED FOR
BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OHIO

D'APPOLONIA